# Resource Book for Science and Technology Consultations

## Volume II

Government of Canada
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# Resource Book
# for
# Science and Technology
# Consultations

## Volume II



Secretariat for Science and Technology Review
Industry Canada
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# Contents



**The opinions expressed in these articles are those of the authors and do not necessarily reflect those of the Secretariat for Science and Technology Review, Industry Canada, or the Government of Canada.**

## Contents of Volume I

# Preface

The purpose of the *Resource Book for Science and Technology Consultations: Volume II* is to provide resource material of special relevance to the review of federal science and technology (S&T) policy. There is no unique source of correct information on S&T policy. The goal of these volumes is to provide relevant data and information and to provoke informed discussion around unresolved and sometimes controversial issues.

While the *Resource Book for Science and Technology Consultations: Volume I* provided a snapshot of S&T performance indicators in Canada and abroad, Volume II focuses on providing background information relevant to specific issues. As such, this volume is intended to be a companion volume to the consultation paper *Building a Federal Science and Technology Strategy* and Volume I. For convenience, this volume contains both the Contents and Index for Volume I as well as for Volume II.

Material for this document has been collected from a variety of sources. In most cases, the articles are drafted as briefing notes rather than as full-scale review articles. Some contain bibliographies or references, which may direct the reader further into the subject.

The articles range from opinion pieces, through background information to detailed mathematical analyses. They are either the result of work of individual authors, or many people, and some represent compilation of pre-existing information.

The term S&T is not restricted to disciplines in the natural sciences and engineering. The public perception of S&T is often of activities in the physical sciences, but this consultation process is equally relevant to the social sciences.

As the editor for both Volume I and Volume II, I would like to thank all who have worked with me under extremely tight deadlines on both publications. I hope that these documents will serve both to inform and stimulate the debate during the development of practical options for a federal S&T strategy.

Adam Holbrook
Editor

# What Canadians Know about Science

*by Ron Freedman**

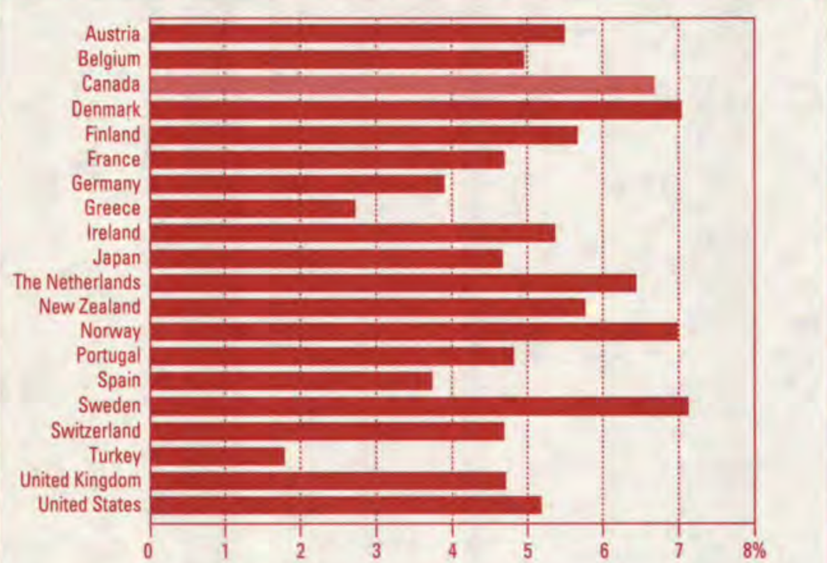
What Canadians know and think about science[1] is important for the future economic well-being of the country and for the ability of individual citizens to lead informed lives and to make knowledgeable choices about matters affecting them.

For example, should private citizens be concerned about the consequences of automated assembly, recombinant DNA, cigarette smoking, ozone depletion, the level of technology in schools, global warming, nuclear power, carbon dioxide emissions, the probability of comets striking the Earth, indoor air pollution or asbestos insulation?

Increasingly, knowledge about science and technology (S&T) is needed to make everyday judgments and choices about daily life.

Related to the question of what Canadians know about science, here used in its broadest sense to include related subjects such as geography and technology, is what they think about it — their attitudes, opinions and beliefs about science.

**Figure 1 — Spending on Education as a Proportion of GDP, Selected OECD Countries, 1989–90**




*Source:* Economic Council of Canada, *A Lot to Learn: Education and Training in Canada — A Summary* (Ottawa: Supply and Services Canada, 1992), p. 23.

## Science Education in Schools

**B**y many measures, Canada enjoys one of the best-endowed systems of education in the world (Figure 1). The average Canadian receives more than 12 years of schooling, second only to the average educational attainments in the United States.

Compared with other countries, literacy rates in Canada are high. But a disturbingly large proportion of young people are neither fully literate nor numerate. The Economic Council of Canada[2] estimates that about 28 percent of young people born in Canada cannot understand a comparatively simple newspaper article. A further 44 percent are unable to perform the calculations needed to add up a restaurant bill or a mail-order form.

Almost every Canadian receives some formal education in mathematics and sciences in elementary and secondary school. Studies show that Canadian student performance on

* Ron Freedman is the principal consultant of The Impact Group in Toronto, Ontario. He has advised both the federal government and the Government of Ontario. He has worked at the Science Policy Research Institute of Sussex University in the United Kingdom, and has been director of the International Science Policy Foundation in London, U.K.

[1] This article refers to science in all its forms, both natural and social. However, as several researchers have found, most people, when asked to comment on science and technology issues generally, are thinking of the natural and life sciences, particularly space and health; see Decima Research, Canadian Teens' Attitudes toward Science and Math Education, presentation to Industry, Science and Technology Canada, 25 November 1991.

[2] Economic Council of Canada, *A Lot to Learn: Education and Training in Canada — A Summary* (Ottawa: Supply and Services Canada, 1992).

international tests varies significantly from one part of the country to another. Many young people drop their science classes as soon as they become optional, usually in grade 10. Thus, relative to other nations, fewer Canadian high school seniors have a strong science component in their academic program.

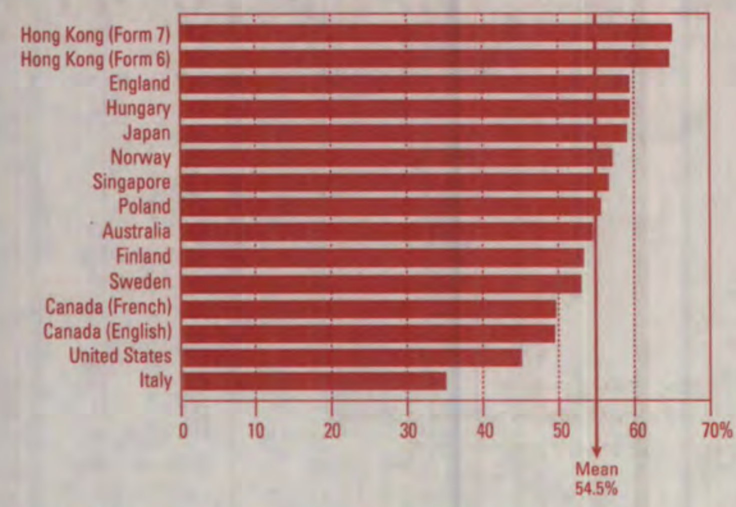
Given these mixed results, one might wonder how much science Canadians know, compared with citizens of other countries.

## Educational Achievement

International comparisons of student achievement in mathematics and science are one way of gauging students' levels of attainment. Analysis by the Economic Council of the mean performance of students in 13 industrialized countries shows that Canadian students' performance in the mid-1980s was about average (Figure 2). Average achievements of Canadian students in two provinces were above the international mean in science and mathematics, and the remainder were below the mean (Figure 3).

Because circumstances vary from country to country, such tests are notoriously difficult to design, administer and interpret. No matter whether they imply good or poor performance, they should always be viewed with caution. Nevertheless, any educational administrator — or parent — would do well to take note of trends and persistent results.

Figure 2 — Science Achievement, Selected Countries, Mid-1980s




*Source:* Cited in *A Lot to Learn: Education and Training in Canada — A Summary,* Economic Council of Canada, Ottawa. Supply and Services Canada, 1992, p. 4.

Figure 3 — Science Achievement, End of Secondary School, by Province, Mid-1980s


*Source:* Cited in *A Lot to Learn: Education and Training in Canada — A Summary,* Economic Council of Canada, Ottawa. Supply and Services Canada, 1992, p. 6.

**Table 1 — Canadians' Knowledge of Basic Scientific Ideas**

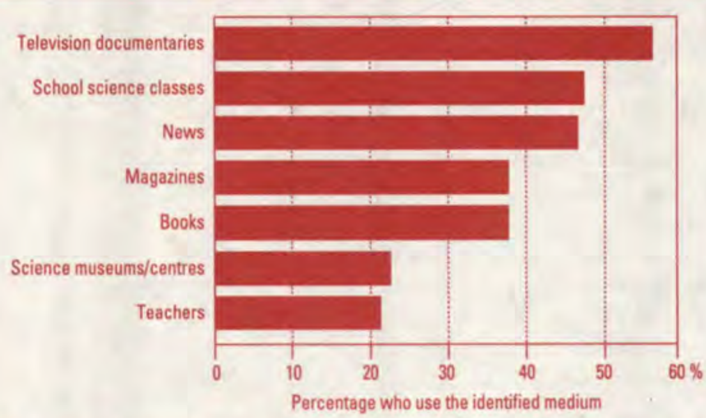
| | Percentage who agree | | |
|---|---|---|---|
| | True | False | Don't know |
| The centre of the Earth is very hot | 84.8 | 4.4 | 10.8 |
| The oxygen we breathe comes from plants | 80.4 | 13.9 | 5.8 |
| Radioactive milk can be made safe by boiling it | 9.6 | 61.3 | 29.1 |
| Lasers work by focusing sound waves | 25.0 | 38.0 | 37.0 |
| Sunlight can cause skin cancer | 95.5 | 2.7 | 1.8 |
| Hot air rises | 96.0 | 1.2 | 2.8 |
| Human beings as we know them today developed from earlier groups of animals | 58.0 | 24.7 | 17.3 |
| Air pollution can cause a greenhouse effect | 85.9 | 4.4 | 9.7 |
| Electrons are smaller than atoms | 46.7 | 19.0 | 34.3 |
| The earliest humans lived at the same time as dinosaurs | 33.8 | 45.9 | 20.3 |
| The continents are moving slowly about on the surface of the Earth | 74.9 | 9.8 | 15.4 |
| Which travels faster, sound or light? | | | |
| • sound travels faster | 20.6 | | |
| • light travels faster | 73.8 | | |
| • don't know | 5.7 | | |
| Does the sun go around the Earth or does the Earth go around the sun? | | | |
| • sun around Earth | 15.2 | | |
| • Earth around sun | 78.4 | | |
| • don't know | 6.4 | | |
| How long does it take for the Earth to go around the sun?[a] | | | |
| • one day | 18.2 | | |
| • one month | 3.9 | | |
| • one year | 65.3 | | |
| • don't know | 12.7 | | |

[a] This question was asked only of those respondents who answered correctly that the Earth revolved around the sun.

*Source:* Edna F. Einsiedel, "Scientific Literacy: A Survey of Adult Canadians" (Calgary: University of Calgary, Graduate Program in Communication Studies, 1990), p. 12, Table 6.

**Young people in school rely heavily for information about science on mass media — newspapers and magazines, radio and television.**

**Sources of Students' Science Information**




*Source:* Decima Research, Canadian Teens' Attitudes toward Science and Math Education, presentation to Industry, Science and Technology Canada, Toronto, 25 November 1991.

## Science Information and Science "Literacy"

Schools, of course, are but one source of information about science. It would come as little surprise to learn that, once they have left the formal school system, most Canadians still rely on mass media for their science information. Thus, about 30 percent of Canadians in 1990 claim they read science magazines, 56 percent regularly watch science programs on TV, and 11 percent listen to science programs on radio.[3]

How do the media present science, and what attitudes, opinions and beliefs do people retain? More importantly, perhaps, to what extent do individuals modify their behaviour in light of the information they acquire? So-called informal science institutions — science centres, planetariums, museums — also play a part in informing the public.

Knowledge of specific science facts is one way to measure public understanding of science. The most comprehensive survey[4] to date of adult Canadians' knowledge of science — their "scientific literacy" — reveals some interesting findings (Table 1).

According to researcher Edna Einsiedel, scientific literacy can be understood to include the following concepts:

- an adequate vocabulary of basic concepts to understand issues on science and technology
- an understanding of the processes or approaches of science
- an understanding of the relationship of science and technology to society.

[3] Edna F. Einsiedel, "Scientific Literacy: A Survey of Adult Canadians," Graduate Program in Communication Studies, University of Calgary, Calgary, 1990, p. 12, Table 6. This research was supported by a grant from the Social Sciences and Humanities Research Council and Industry, Science and Technology Canada.

[4] Ibid.

To begin, it is worth pointing out that no question posed in Table 1 was correctly answered by all respondents in the survey. Thus, while 96 percent knew that hot air rises, 1.2 percent did not know, and 2.8 percent could not answer. Centuries after Italian astronomer Galileo shocked the world by declaring that the Earth revolves around the Sun, two in 10 individuals still did not know this fact. An even larger number — nearly 35 percent — did not know that it takes one year for the Earth to circle the sun. More than half of survey respondents were apparently unaware that the age of dinosaurs ended long before human beings populated the planet. If these findings are indicative, it would appear that the notion of universal scientific literacy is still some way off.

On the other hand, many people (74.9 percent) know something of the tectonic plate theory that describes the slow movement of the continents over the surface of the Earth. A very high proportion (95.5 percent) understand that sunlight can cause skin cancer, and that boiling does not render radioactive milk safe (61.3 percent). How should these findings be interpreted? Is the "glass" of scientific literacy half empty . . . or half full? One way is to compare Canadians' pattern of responses with that of people in other countries. Table 2 makes such a comparison for Canada, the U.K. and the U.S.

Although correct responses to individual questions vary significantly, the overall pattern of correct and incorrect responses is similar among the three countries. Taking all questions together, Canadians replied correctly on average 69.3 percent of the time, while 64.8 percent of Britons and 66.1 percent of Americans knew the right answer. In all three countries, respondents scored highest on the fact that hot air rises. But only 38 percent of Canadians and 36 percent of Americans knew that lasers work by focusing light waves, not sound waves. And only 30.9 percent of Britons knew that electrons are smaller than atoms.

Table 2 — Canadian, British and American Comparisons on Knowledge of Basic Science Ideas

| | Percentage who responded correctly | | |
|---|---|---|---|
| | Canada | U.K. | U.S. |
| The centre of the Earth is very hot | 84.4 | 86.3 | 80.3 |
| The oxygen we breathe comes from plants | 80.4 | 59.9 | 80.6 |
| Radioactive milk can be made safe by boiling it | 61.3 | 65.1 | 64.1 |
| Lasers work by focusing sound waves | 38.0 | 41.8 | 36.0 |
| Sunlight can cause skin cancer | 95.5 | 93.5 | 96.9 |
| Hot air rises | 96.0 | 96.7 | 97.0 |
| Human beings as we know them today developed from earlier groups of animals | 58.0 | 79.0 | 51.7 |
| Electrons are smaller than atoms | 46.7 | 30.9 | 42.7 |
| The earliest humans lived at the same time as dinosaurs | 45.9 | 46.2 | 36.8 |
| The continents are moving slowly about on the surface of the Earth | 74.9 | 71.7 | 80.1 |
| Which travels faster, sound or light? • light travels faster | 73.8 | 74.7 | 76.1 |
| Does the sun go around the Earth or does the Earth go around the sun? • Earth around sun | 78.4 | 62.8 | 72.5 |

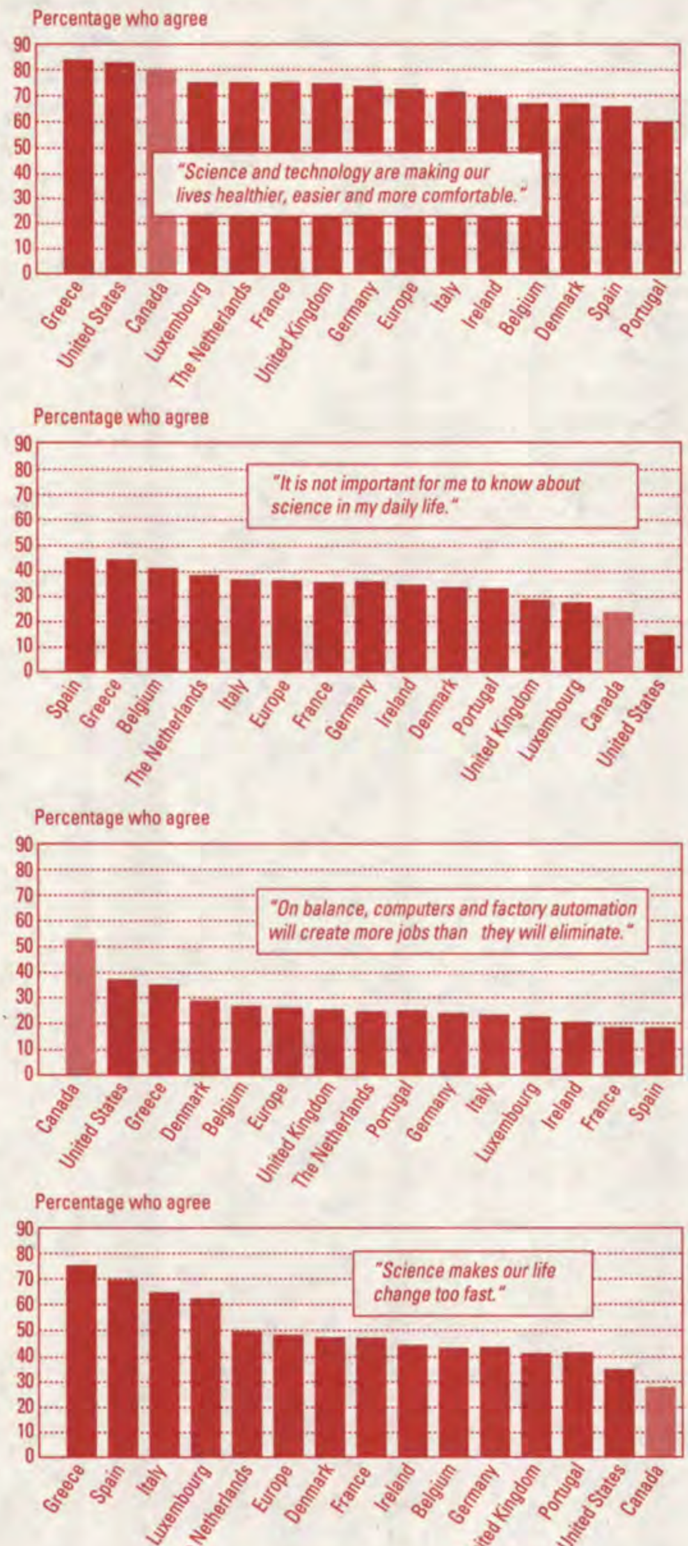
*Source:* Einsiedel, *op. cit.*, p. 14, Table 7.

Unfortunately, being able to measure Canadians' levels of factual knowledge of science or their knowledge levels compared with that of people in other countries does little to help answer the basic question: How much knowledge is enough? Clearly, not all citizens need to have a depth of scientific knowledge equal to someone at the doctoral degree level. Some might argue that it is not so important how much science knowledge a country has, as how much it is able to apply. This is being reflected, in part, in the entry level requirements for jobs, and in the increasing overall technological sophistication of the workplace.

## Canadian Attitudes toward S&T

Along with the question of what Canadians know about science is what they think of it. For instance, do they see science as a positive force in society? What about for them personally? How do they think science should be supported by governments? Canadian and international studies of the attitudes of youth and adults provide some interesting information.

**Figure 4 — International Comparisons of Public Attitudes toward Science and Technology**




*Source:* National Science Board, *Science & Engineering Indicators — 1991* (Washington, D.C.: U.S. Government Printing Office, 1991), p. 184, Figure 7-16.

Canadians prove themselves to be quite open to science on a broad range of measures (Figure 4). Most agree that "science and technology are making our lives healthier, easier and more comfortable." Very few of us think that "it is not important . . . to know about science in daily life." Canadians appear to be much more open to new technology in the workplace, and agree that "on balance, computers and factory automation will create more jobs than they will eliminate." Conversely, Canadians are less inclined than citizens of most other countries to feel that "science makes our way of life change too fast."

A very high proportion of survey respondents declare themselves to be very or at least moderately interested in or informed about science (Table 3). However, there are considerable gaps between levels of interest and informedness.

For example, a total of 95.2 percent of Canadians are very (59.3 percent) or moderately (35.9 percent) interested in medicine and health topics which appear in the news. But fewer people, at 84.6 percent, feel they are very or moderately well informed about medicine and health. On the whole, Canadians are very interested in science and technology, but do not feel they are as well informed as they might be.

Sadly, as the gap between interest and informedness indicates, most Canadians are unaware of Canadian scientists and their achievements. Almost two thirds of individuals (63.6 percent) could not name a single Canadian scientist. About one in six (16.2 percent) was able to name Frederick Banting, the co-discoverer of insulin, but very few (1.8 percent) were able to name his colleague, Charles Best. Among living scientists, only David Suzuki — now a television personality — came to mind among any significant number of people (15.1 percent). John Polanyi, one of only two Canadian Nobel Prize winners at the time, was named by four persons in a thousand.[5]

[5] The other prize winner at the time of the survey was Gerhard Hertzberg, Canada's first Nobel Prize winner. Since then there has been a third prize winner, Michael Smith.

When it comes to careers, Canadians appreciate the advantages of science. When asked to rank a variety of career choices for today's youth, adult respondents consistently placed computer programming and medicine at the top, far above law or business (Figure 5). However, not all science careers fared quite as well. Engineering was recommended about as often as law, but biology was recommended by only 8 percent of individuals.

## Attitudes on Expenditures on S&T

Canadians also recognize the importance of science to the country's economic future. Three in four Canadians feel it is important to develop our own technology in resources, manufacturing and services, while around seven in 10 also think it is important to keep up to the leading nations in these areas.[6]

When asked who they thought should be responsible for carrying out either fundamental long-term research or applied research, a plurality of Canadians had definite opinions (Figure 6). With regard to fundamental long-term research, most people (45 percent) felt that universities were the most appropriate locale for this type of work. However, a significant proportion also felt that industry (29 percent) and the federal government (26 percent) should engage in this type of research. On the matter of applied research, respondents overwhelmingly felt that industry (61 percent) was the preferred venue, rather than universities or the federal government (19 percent each).

On the matter of who should fund fundamental long-term or applied research, opinion was somewhat less definite (Figure 7). Over half of respondents (53 percent) said the federal government should fund most of the fundamental long-term research carried out in Canada. But a significant number (32 percent) said industry should also fund this kind of research. Fewer people (14 percent) felt that provincial governments should fund fundamental research. Most people felt that applied research should be funded by

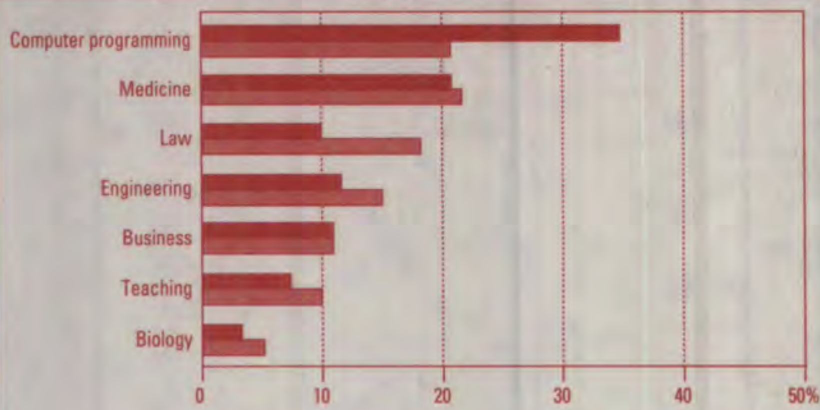
[6] Decima, *Report to the Ministry of State for Science and Technology on Public Attitudes toward Science and Technology*, Toronto, January 1988.

**Table 3 — Interest in and Informedness on Topics in the News**

| | Interest level: | | Informedness level: | |
|---|---|---|---|---|
| | very | moderate | very | moderate |
| | (percentage who agree) | | | |
| Agriculture, farm stories | 16.6 | 47.3 | 11.6 | 44.8 |
| Sports | 23.9 | 38.6 | 31.9 | 34.9 |
| Business, economics | 30.1 | 51.2 | 21.1 | 52.9 |
| New scientific discoveries | 45.1 | 44.0 | 16.0 | 55.4 |
| Entertainment | 26.4 | 57.7 | 25.9 | 53.0 |
| Space exploration | 29.9 | 44.9 | 14.1 | 51.5 |
| Politics | 31.5 | 45.1 | 33.3 | 44.7 |
| Computers, other communication technologies | 23.8 | 49.2 | 14.3 | 46.1 |
| New innovations, technologies | 38.0 | 48.5 | 12.1 | 53.6 |
| Environment | 58.9 | 38.5 | 35.5 | 52.8 |
| Medicine and health | 59.3 | 35.9 | 29.1 | 55.5 |

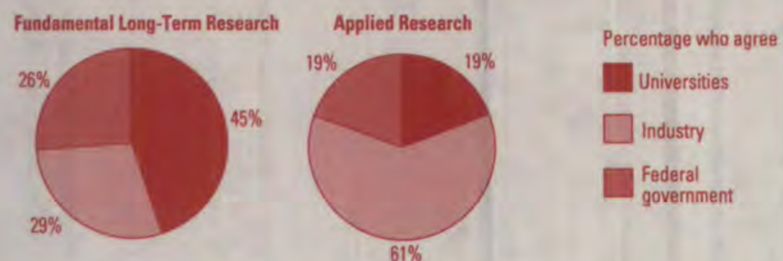
*Source:* Einsiedel, *op. cit.*, p. 10, Table 3.

**Figure 5 — Ranking Career Choices for Today's Youth**




*Source:* Einsiedel, *op. cit.*, p. 2, Table 1.

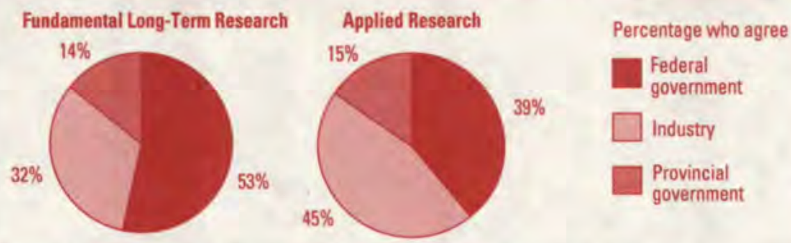
**Figure 6 — Responsibility for Conducting Fundamental Long-Term and Applied Research***




* Question asked: There are a number of groups in the country involved in research and development. Which group do you think should carry out most of the fundamental long-term research? Which should carry out most of the applied research?

*Source:* Decima, *op. cit.*, p. 8, Table 4.

**Figure 7 — Responsibility for Funding Fundamental Long-Term and Applied Research[a]**




[a] Question asked: Which group should fund most of the fundamental long-term research carried out in Canada? Which group should fund most of the applied research?

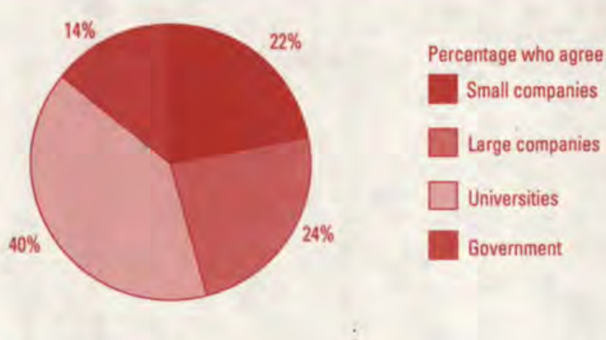
*Source:* Decima, *op. cit.*, p. 9, Table 5.

**Table 4 — Perceptions of Government Spending**

| | Too much | About right | Too little |
|---|---|---|---|
| | | (percentage who agree) | |
| Health care | 5.1 | 30.4 | 62.1 |
| Pollution reduction | 2.0 | 10.6 | 84.3 |
| Education | 4.2 | 32.8 | 60.4 |
| Scientific research | 10.4 | 33.6 | 45.0 |
| Helping older people | 1.9 | 29.4 | 65.7 |
| Conservation | 2.7 | 34.0 | 56.8 |
| Helping people on low incomes | 10.5 | 31.5 | 54.3 |
| Weapons/national defence | 56.6 | 23.4 | 14.0 |

*Source:* Einsiedel, *op. cit.*, p. 24, Table 14.

**Figure 8 — Sector Most Likely to Produce Innovations and Breakthroughs in Science and Technology**




*Source:* Einsiedel, *op. cit.*, p. 12, Table 7.

industry (45 percent), but a significant number felt there was a federal government role (39 percent). Few people (15 percent) felt applied research funding was a responsibility of provincial governments.

## Canadians' Attitudes on the Role of Government in S&T

What do people think about government spending on science relative to other government expenditures? Opinion varies profoundly, depending on the purpose of the spending (Table 4).

A large plurality of individuals (57 percent) surveyed in 1990 believed that too much is being spent on developing weapons for national defence.[7] Only 14 percent believed too little is being spent, and 23 percent thought spending is about right. In contrast, fully 84 percent of Canadians surveyed felt too little is being spent on reducing pollution. Only 2 percent felt the amount spent is too much, and 11 percent thought spending is about right. Other subjects received varying levels of support.

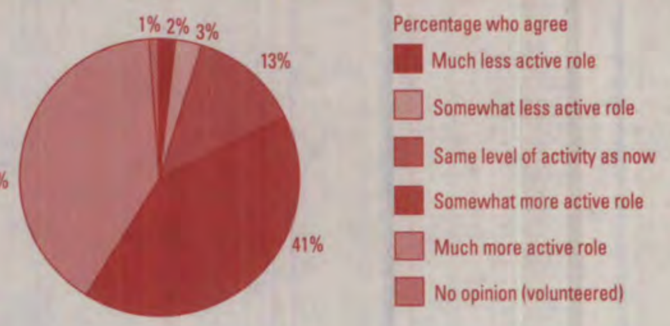
Scientific research as an end in itself, except for defence, had the lowest level of support among the spending alternatives, as measured by people who felt too little is being spent. Forty-five percent of people felt too little is spent on scientific research, whereas 34 percent felt spending is about right and 10 percent felt it is too much. This split view may be linked to a perception that some research is not conducted in support of peoples' other priorities, such as the environment. There may be an important message here for supporters of "basic" or "curiosity-oriented" research.

In general, such surveys indicate that Canadians feel the federal government should be more involved in funding research, and industry should be more involved in carrying it out. This sentiment is partly reflected in opinions regarding the sector that is most likely to produce scientific and technological innovations and breakthroughs (Figure 8). Equivalent numbers expect these advances to come from companies (46 percent) and universities (40 percent), but few expect them to come from government (14 percent).

[7] Note that since 1990, opinions may well have shifted, as views on these topics are more likely to fluctuate with external events.

However, respondents were extremely positive about the role they felt the federal government should take in the development of Canadian technology. Over 80 percent felt the federal government should take a somewhat or much more active role in the development of technology, compared with 18 percent who felt the current role or a diminished role is appropriate (Figure 9).

Figure 9 — Role the Federal Government Should Play in the Development of Canadian Technology




*Source:* Einsiedel, *op. cit.*, p. 37, adapted from Decima poll 1617, question 20.

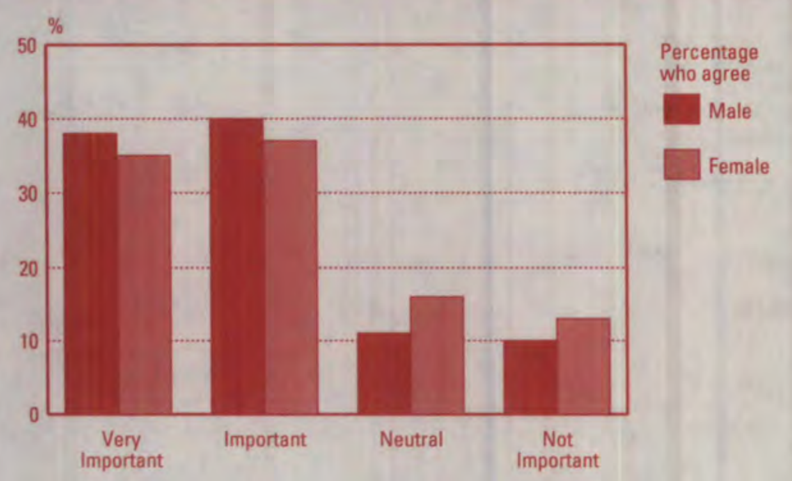
## Attitudes of Young People

What about the attitudes of young people in particular? Human Resources Development Canada projects that jobs requiring total years of training in excess of 16 will almost double during the present decade relative to actual levels of training in the 1991 labour force (see Volume I, p. 1). The number of jobs requiring 16 years of training or less will shrink significantly. This implies that the entry-level requirements for most jobs will be increasing.

Research indicates that Canadian youths hold some interesting attitudes toward science. Among Canadian teens surveyed, 86 percent believed that math will be important to their future success, while 75 percent believed science will be important (Figure 10).

Interestingly, though, further analysis shows that the perceived importance both of science and math decreases as education levels increase. This may be related to the fact that science and math tend to be compulsory in elementary and intermediate grades, but not at senior levels. The varying degrees of importance that is attributed to math and science can be explained in part by the fact that more teens thought future jobs would require a basic knowledge of math rather than science.

Figure 10 — Teen View of the Importance of Science and Math to Future Success



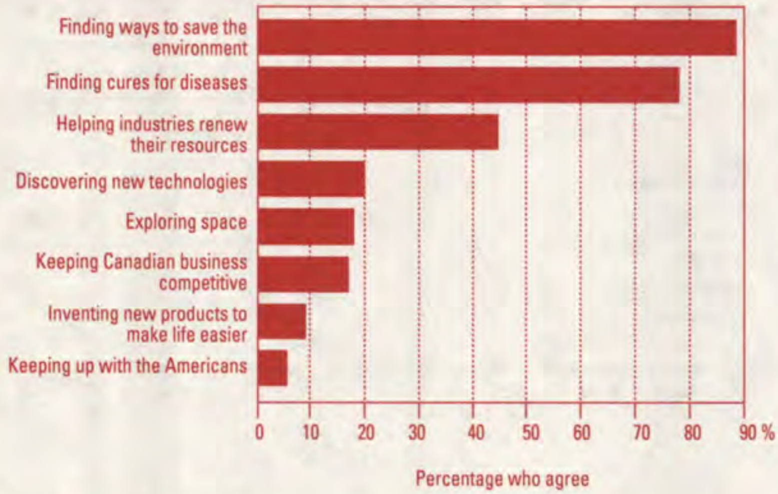

*Source:* Industry, Science and Technology Canada, *Pepsi Street Beat Wave IV* (Ottawa: ISTC, 1993), p. 17, Table 11.

**Table 5 — Teens' Interest in Career Options**

| | National average | Female | Male |
|---|---|---|---|
| | (percentage very or somewhat interested) | | |
| Entertainment | 63 | 71 | 56 |
| Sports | 57 | 47 | 67 |
| Science and technology | 54 | 44 | 63 |
| Business | 47 | 46 | 48 |
| Arts | 45 | 55 | 35 |
| Care giving/Social work | 45 | 69 | 22 |
| Government | 22 | 21 | 22 |

*Source:* Estimates by Industry Canada based on information presented by Decima on 25 November 1991.

**Figure 11 — What Teens Consider to Be the Most Important Science or Technology Issues**




*Source:* Estimates by Industry Canada based on information presented by Decima on 25 November 1991.

**Table 6 — Can Science and Technology Solve Problems Caused by Pollution?[a]**

| | Grade 10 | Grade 12 |
|---|---|---|
| | (percentage who agree) | |
| Science and technology will not be able to solve problems caused by pollution, because the problems are so bad that it would cost too much | 9 | 8 |
| Science and technology alone cannot solve problems caused by pollution | 55 | 56 |
| Science and technology can solve problems caused by pollution because science and technology have been successful in solving such problems in the past | 34 | 32 |
| No answer | 3 | 4 |

[a] Number responding: Grade 10 — 386; Grade 12 — 331.

*Source:* The Impact Group, *Measuring Students' Understanding of Science in its Technological and Social Context — Volume 2: Validating the Instrument* (Toronto: Ontario Ministry of Education and Training, 1993).

When teenagers were asked about the career options in which they were very or somewhat interested, science and technology careers fared quite well, compared with alternatives such as entertainment and sports (Table 5), and they even exceeded business careers for males.

Asked what they believed to be the most important science or technology issues, teens clearly specified environmental and medical issues (Figure 11). In their opinion, helping industry renew its resources, discovering new technologies, exploring space and keeping Canadian business competitive ranked well below these quality-of-life issues.

Can science and technology solve environmental problems? A 1990 study of Ontario students' attitudes by The Impact Group shows that teens are quite sophisticated in their views (Table 6). Most (55 percent) agreed that science and technology cannot solve problems on their own, implying that environmental problems have a larger social aspect. A large number (34 percent) felt that S&T can solve pollution problems, because of past successes. A small number (9 percent) felt that the costs would be prohibitive, even if the science and technology worked out.

What of spending on research? Again, teen views were quite sophisticated (Table 7). A majority (55 percent) felt that if Canada spent more money on research in science and technology, the country would not necessarily become wealthier, depending on which areas were selected. Twenty percent thought Canada would become wealthier with increased spending, but an equal number thought it might become poorer, due to the opportunity cost of the investments.

Teens confirmed four types of activities that are most likely to increase their enjoyment of math and science courses (Table 8). They felt activities that make the learning of science more "relevant" and more "hands-on" would substantially increase their enjoyment of courses — and presumably their propensity to stick with them.

## Conclusion

Is the Canadian "glass" of knowledge and attitudes toward science half empty or half full? How does Canada compare with other nations? How much science knowledge and awareness are enough? Although debate on these questions is spirited, there is comfort in the evidence that Canadians are open toward science and appreciate its importance to themselves and society at large. The challenge for society is to translate this understanding and awareness of science into individual and social action.

Table 7 — If Canada Spent More Money on Research in Science and Technology...[a]

| | Grade 10 | Grade 12 |
|---|---|---|
| | (percentage who agree) | |
| Canada would become a wealthier country | 20 | 28 |
| Canada might or might not become a wealthier country<br>It would depend on what science and technology were chosen | 55 | 59 |
| Canada might become poorer, because other ways of making Canada wealthier would suffer | 20 | 10 |
| No answer | 5 | 5 |

[a] Number responding: Grade 10 — 386; Grade 12 — 331.
*Source:* The Impact Group.

Table 8 — Impact of Changes in Science/Math Courses on Enjoyment of the Courses

| | Enjoy a lot more | Enjoy a little more | Make no difference | Enjoy a little less | Enjoy a lot less |
|---|---|---|---|---|---|
| | | | (percentage who agree) | | |
| More experiments | 40 | 35 | 18 | 4 | 1 |
| "Mentor programs" where you go to work in a job using science or math for a day | 41 | 31 | 19 | 4 | 3 |
| More helpful in day-to-day life | 31 | 41 | 24 | 1 | 0 |
| More hands-on work | 36 | 33 | 19 | 8 | 2 |

*Source:* Adapted from Industry, Science and Technology Canada, *Pepsi Street Beat Wave IV* (Ottawa: ISTC, 1993), p. 24, Table 17.

# Canada and the National System of Innovation

*by John de la Mothe**

The term National System of Innovation is used here to describe a part of the national economy that, among other things, puts science and technology (S&T) to productive use. Schumpeter (1934) argues there are five types of innovation:

- the introduction of a new good
- the introduction of a new method of production
- the opening of a new market
- the acquisition of a new source of supply of raw materials
- reorganization of the industrial unit.

S&T operate principally on the first two types of innovation: new products and new processes. In the modern context, these would include government products and programs such as social programs and health care programs. The Organisation for Economic Co-operation and Development (OECD 1991) in its *Oslo Manual* sets out a theoretical and practical approach to understanding and measuring innovation resulting from scientific and technological activities. This work has been expanded after the completion of its Technology and the Economy Program (OECD 1992) to current systems analysis studies on complete national systems of innovation.

The purpose of this paper is to describe the complex networks that are collectively described as "national systems of innovation" and to link them to the Canadian situation.

## The Economic Environment

Canadians generally accept the idea that our economy — our ways of maintaining high standards of living, of creating wealth, and of distributing that wealth — is undergoing a major transition has become widespread and accepted. In acknowledging this shift, we have rather routinely said that the key to our future lies in science and technology, research and development, and innovation. We have said that the new economy is somehow different, that it is knowledge-based or information-based. We have said that the economies of the OECD nations have "gone global." But for a long time, we have had only vague ideas about what all this meant or what we could do about it.

Our framework for understanding economic growth and trade has worked well for the better part of a century. Yet in this older view, the new intellectual resources upon which we now rely never really played a big part. Moreover, the elements needed for growth were all thought to be contained within the borders of the nation state. Thus, it was not surprising that Canada exported minerals and timber, Brazil exported rubber and bananas, Portugal exported wine, and the United States exported steel. Every nation — and the firms within each nation — was thought to have a natural comparative advantage, and competitiveness was defined by such factors as price, costs, exchange rates and productivity.

But times have changed. Growth can no longer be generated by simply taking resources from the environment and selling them. More than ever before, performance specifications, quality and design have become more important than price competition. Value-added has become increasingly a matter of what we do

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rather than what we have, and mass production (with its volumes of uniform, undifferentiated, products) is rapidly giving way to lean production (which is fast, flexible and capable of delivering custom products) and service.

As for the global aspects of the new economy, there is no doubt that international trade has been one of the main engines of growth since World War II. With the continuous liberalization of trade, which has reduced the average tariff barrier across the OECD nations from 46 percent to less than 5 percent, world trade flows have increased between 1950 and 1975 by more than 500 percent, compared with an increase in world output of only 200 percent.[1] But international investment and technology flows have overtaken product-based trade. This is a subtle but important shift and suggests a number of changes. For example, traditional trade is largely based on tangible goods. Investment and technology flows, on the other hand, are highly intangible; that is, they are not embodied as a widget or a machine, but are encoded as information. One is material intensive; the other is knowledge intensive.

Wealth creation and economic growth are often used interchangeably. Economic growth is a function of income, which itself is a measure of the flow of some resource of value (usually money, but it could include natural resources, intellectual property or human capital). On the other hand, wealth is a measure of the existing inventory or stock of a valued resource. The stock of wealth is therefore a factor in producing income. Wealth in this sense is in effect a "cause" of income, rather than the other way around. Surplus income may be used to support higher levels of consumption or may be used to increase investment, which in turn adds to the stock of wealth.

A society can enhance its productive capacity in two ways:

- through investment, which adds to the stock of wealth, including physical and human capital
- through innovation, which improves the productivity of physical and human capital.

[1] Based on statistics from OECD and United Nations Statistic Office.

Innovation is central to many of the shifts resulting from the globalization of the major economies. Or more precisely, it is the innovative capacity of firms that is the major driving force behind economic growth and a country's ability to derive the benefits from international trade. Understanding the ways in which firms access and use external sources of knowledge is important for science, technology and innovation policy. And the availability of intelligent infrastructure, ranging from information highways and high-technology networks to universities, provides the environment within which innovation can thrive.

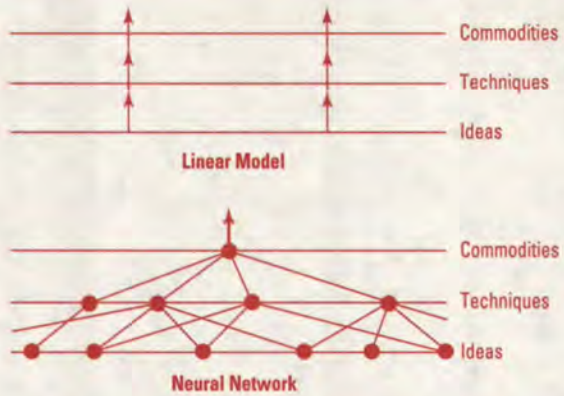
These important facts have led firms and public policy circles to pay increased attention to the ways in which they can strengthen their innovative capacity and hence Canada's competitive position. But in order to discuss these ideas, we need a new framework to help us grasp how the system really works and how it does not. What follows is a brief sketch of this framework.

## Linear Model of Innovation

The linear model of innovation has been used to explain the links between research and development (R&D) and economic performance. It is so highly abstract that it does not really explain the complexities of innovation in a real world. Yet it still informs many policy discussions. This fact alone has led economic historian Nathan Rosenberg (1991) to say it "is dead, but it won't lie down."

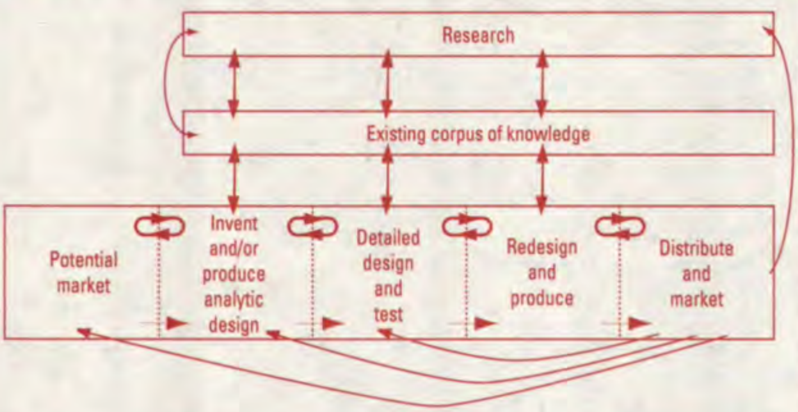
The linear model has three principal variants referred to as science-push, technology-pull and market-pull. In the science-push variation, product development and commercialization are the result of broad-based, undirected basic research. Basic science discovers new principles or mechanisms about the natural world that — once a practical use is thought of — get taken up in more focused or applied R&D, which in turn leads to experimental development, design, prototyping and ultimately market launch. In this model, knowledge is discovered in universities, passed on to firms through publications, patents and other forms of scientific correspondence, and on to final customers in the form of a product or service.

Figure 1 — Neural Network System of Innovation




*Source:* J. Ziman, "A Neural Network Model of Innovation," *Science and Public Policy* 18 (February 1991).

Figure 2 — Chain-linked Model of Innovation




*Source:* Organisation for Economic Co-operation and Development, *National Systems of Innovation: General Conceptual Framework*, DSTI/STP/TIP 94 4 (Paris: OECD, 1994).

The technology-pull model is essentially the same except that it shifts the emphasis away from scientists and onto engineers. Here, engineers working within firms come upon a technical problem dealing either with the production process or with new product realization. They pass the problem down the chain for the scientists to fix — through basic research — and then the solution is passed up through to market launch.

And in the market-pull version, the stimulus for basic research and new technology comes, not from a knowledge-based problem, but directly from the market.

Of course, there are numerous flaws with all of the variants of the linear model. They are all highly stylized and thus do not accurately reflect the way real labs or businesses operate. They rely almost exclusively on the R&D process, thus excluding most of the social, organizational and financial factors upon which most innovation and economic growth are based. They artificially separate the process of knowledge creation into a series of hermetically sealed activities — basic and applied research, experimental development, design, etc. — that few in research or business would recognize. They have also, at least implicitly, separated scientists, engineers, accountants and marketers and, in so doing, have assumed that each possesses a clear set of discrete, non-transferable and inflexible skills.

## Innovation as a Neural Network

In an attempt to move beyond this simplified view, and recognizing both the high information content of innovation and the unpredictability that underpins much creative research, some researchers have developed so-called neural network models of innovation (see Figure 1). In these, ideas, techniques and commodities are all interconnected, attesting to the serendipity of innovation. The advantage of this kind of approach is that it places the cognitive nature of innovation and the flows of knowledge between actors at centre stage. However, it does little to help in either the analysis of innovation and its links to economic performance or in the management of the process.

## Chain-linked Model of Innovation

A more satisfying model is the chain-linked model of innovation (Figure 2), which puts its emphasis more systematically on the interrelatedness of the different phases of the innovation process and on the feedback mechanisms that are involved. In this conceptualization, knowledge and research are not dissected as they are in the linear models, and artificial distinctions — such as that between competitive and precompetitive research — become rather obsolete.

## National System of Innovation

The benefits of this chain-linked model are captured and extended in a framework that has been growing in intellectual coherence and policy relevance throughout the OECD countries in recent years. This framework is widely known as the "national system of innovation." The idea of a national system goes back more than 150 years to the writings of German economist Freidrich List in 1841 in his *National Systems of Political Economy.* But more practically, the idea — as applied to innovation — has grown in currency through the analytic and empirical efforts of B. A. Lundvall at the OECD, Christopher Freeman at the University of Sussex and their colleagues (see works by Lundvall and Freeman in the Select Bibliography at the end of this essay).

The benefits of this approach are myriad. For example, there is a widespread conviction that in the new global economy, firms increasingly use external sources of technical knowledge to stay competitive. They may do so for a number of reasons. They may need to keep up with the increasing pace of technical change in their industry. They may need to share the increasing costs or risk of doing research. They may need to cope with the growing multidisciplinarity of scientific knowledge upon which much innovation is based. Or they may need to gain access to new markets by cooperating with other, knowledge-intensive firms.

The policy relevance of this approach also stems from a number of sources. First, policies aimed at improving the innovative capacity of an economy — and of the business sector in particular — need to be grounded in a sound understanding of the way that firms in a country access information and know-how. Second, governments are playing an important role in the development of intelligent infrastructure and technological networks. And third, governments are increasingly working with firms in an effort to negotiate access for them into new markets such as is found in the new European Union or Mexico.

Moreover, for a long time, the principal emphasis or preoccupation in science, technology and innovation policy has been on fostering the generation of knowledge, rather than on its distribution, improving access to knowledge and applying knowledge. Surely, for a country like Canada, which contributes only about 4 percent of the world pool of S&T knowledge and which ranks sixth among the Group of Seven (G-7) most developed nations in terms of gross expenditure on R&D as a percentage of gross domestic product,[2] this kind of orientation needs to be carefully rethought.

The essential rationale for a national systems approach was outlined by Chris Freeman (1988):

> ***the rate of technical change in any country and the effectiveness of companies in world competition in international trade in goods and services,*** **does not depend simply on the scale of their research and development. . . .** ***It depends upon the way in which the available resources are managed and organized, both at the enterprise and the national level.*** **The national system of innovation may enable a country with limited resources . . . to make very rapid progress** ***through appropriate combinations of imported technology and local adaptation and development.*** (emphasis added)

Clearly, this demarcation has important implications for a country like Canada where the S&T policy debate has long focused principally on the level of spending on R&D and on the scarcity and scattered distribution of resources for innovation due to the geographic and demographic realities of the country.

A number of broad characteristics become prominent with the adoption of a national systems approach. First, it emphasizes that firms are the principal sites for the creation of wealth and cannot be viewed in isolation, but as part of a **network** of public and private sector institutions whose activities and interactions initiate, import, modify and diffuse new technologies. Second, it emphasizes the **linkages** (both formal and informal) between institutions.

[2] Based on statistics from OECD and United Nations Statistic Office.

Third, it emphasizes the **flows** of intellectual resources between institutions. Fourth, it emphasizes **learning** as a key economic resource. And fifth — albeit counter-intuitively, given our global economy — it asserts that geography and **location** still matter. In a sense, the synergies of a national systems approach rely on local systems of innovation.

Essentially, then, the idea of a national system of innovation asserts that a country's economy is more than the simple sum of its firms' activities, but is rather the result of synergies that arise from the interactions between economic actors in a country. In addition, a system of innovation can be considered important because of its distributive power; that is, the system's ability to distribute existing knowledge for recombination.

One of the originators of the concept of national systems, B. A. Lundvall (1992), argues that an important advantage of this framework is that it allows analysts to examine the **differences** in the ways that countries, or even individual industries in various countries, organize their knowledge-creating or knowledge-using activities. Such variance can often be traced to differences in geography, language and culture. He distinguishes five areas where differences between national systems might occur. These are in the internal organization of firms, in interfirm relationships, in the role and expectations of the public sector, in the institutional setup of the financial sector, and in the intensity and organization of R&D.

In dealing with innovation, it is useful to clarify what is meant by the term. Some have said simply that innovation is anything a firm does to stay competitive. But this is not rigorous. Indeed, recall the last category suggested by Schumpeter. This involves changes to the organization of a firm, an industry or the way in which industries act within a society, both inside, outside and between institutions. Strategic alliances and joint ventures, which are often designed to gain access to new technologies or new capital, can be thought of as innovations in that they can allow small firms, for example, to act big and be present in numerous locations or markets at once. Clearly, then, R&D is not the only way a firm or a nation can innovate and generate jobs and wealth.

Of course, firms do not wish to innovate only once: they need to institutionalize the innovation process so that it becomes part of their corporate culture and makes them capable of innovating continuously. In a sense, they need to learn — and remember —how they innovated in the first place. Firms such as IBM and Bell-Northern Research are famous for having done just this. But as the experience of IBM in the late 1980s shows, it is entirely possible for a once-innovative firm to forget.

More recently, however, a number of big firms like IBM and parts of Chrysler have deliberately flattened their hierarchies into what they call a federation of firms. In effect, they are trying to enjoy the benefits of being both big and small. By so doing, they can get closer to their customers, closer to their suppliers and closer to the communities in which they operate. They can act faster, be more flexible or responsive to both new pressures from competitors and new opportunities from customers, and pay more attention to quality. These are all earmarks of innovative firms in today's global economy.

## Knowledge

Knowledge is a term used to refer to a lot of different but economically important activities and processes. It is particularly important — indeed, it is critical — to any understanding of the new economy and the changing nature of growth. The advantage of knowledge is that it is a durable and public good. That is, it doesn't wear out or get used up and, when codified in the form of a patent application, a published article, etc., it is available to everyone. Multiple or joint use does not diminish the value of knowledge.

An important element of thinking about research and innovation in terms of knowledge is made clear by the father of John Polanyi, one of Canada's own Nobel Prize winners. Michael Polanyi (1959) reminds us that there is explicit knowledge and tacit knowledge. He describes the latter by saying simply but powerfully that "we know far more than we can say." Upon reflection, this seems obvious, but it captures the intangibility of the innovation process.

Beyond this, Lundvall and Johnson (1992) have differentiated between various types of knowledge. These they describe as follows:

- **Know-how** usually refers to some form of knowledge that enables someone to complete an observable task, without necessarily being aware explicitly of how the task was done. Manual skills are typically referred to as know-how, but it may also be used with reference to the organizational abilities of individuals or social groups. Tacit knowledge is largely know-how.
- **Knowing what** refers principally to factual propositions like tax codes, regulatory or legislative details, commercial documents like balance sheets, as well as the kinds of knowledge that are needed for the identification and labelling of phenomena in the natural world.
- **Knowing why** refers to knowledge as understanding. Traditional conceptions of scientific knowledge tend to fit largely within this category.
- **Knowing who** refers to one's understanding of the identities, reputations and the relations between the various actors within organizations. The greater part of an individual's knowledge about other human beings is gained through social interaction and is privately held. As a result, it is not something that can be confirmed. Its validity is tested through judgment. Social know-who thus parallels organizational know-how, except that it is, in direct terms, practically useless economically.

A further distinction should be made between information and data. Data refer to non-ambiguous and elementary bits of information. Information, then, can be thought of as structured or formatted data that are ready for transmission. From this perspective, knowledge can be considered as the conceptual and factual contexts that enable individuals or organizations to interpret or give meaning to messages. Of course, thinking about knowledge and information in an economic sense (that is, as a commodity) allows us to begin thinking about their transfer into use.

Not surprisingly, when we think of innovation, we often view scientists, engineers and technicians as different and perhaps special kinds of knowledge workers. Relying on this sort of view, or restricting our view of the system to the very highly trained and talented individual researchers, should be avoided. Instead, the critical interpretation ought to be one that is based on the social organization of knowledge, the distribution of knowledge and production.

Today, what fundamentally distinguishes scientific workers from others is not their methods, the nature of the knowledge they generate, nor the system through which they obtain financial support. Instead, research throughout the OECD strongly suggests it is the reward structures that exist for knowledge workers as well as the social and political arrangements put in place to organize this work, such as laboratories, institutes and universities.

The crucial distinction from the national system point of view has to do with the ideas of an open community of scholars and the proprietary research community. For the open community, research and the research community are organized around the mission of adding to the public stock of knowledge. This is largely paid for from the public purse (that is, tax dollars) and is made generally and openly available across borders through journals, published articles, scientific correspondence, lectures and so on. For the proprietary research community, the economic value of research is appropriated by the organizations (largely firms) that sponsor or undertake it. This can be contained in the form of intellectual property rights, patents, licenses and so on.

**Table 1 — Comparison of Forms of Economic Organization**

| | Markets | Hierarchies | Networks |
|---|---|---|---|
| Basis | contract | employment | complementarity |
| Communication | prices | routines | relations |
| Conflicts | haggling | administrative fiat | reciprocity/reputation |
| Flexibility | high | low | medium/high |
| Climate | precision | formal | mutual benefits |
| Relations | independence | dependence | interdependence |

*Source:* OECD, *Technology and the Economy: The Key Relationships.* DSTI/STP/TIP(94)3. Paris: OECD, 1992.

## Transfer

The transfer of knowledge is perhaps the most important flow within a national system. But before this can happen, a first step is necessary in the process of making research commercial; namely, the transformation of knowledge into information, usually referred to as codification. Whether knowledge is in codified form — patent, article, etc. — determines in part the cost of acquiring knowledge.

Within a national system of innovation, there are numerous ways to transfer knowledge. The most important of these are contractual tools, social networks and information systems or coordinating mechanisms. Examples of contractual tools are strategic alliances, joint ventures, licensing and distribution arrangements. Social networks are particularly important, not only because it is ultimately individuals who transform, use, modify and diffuse knowledge, but also because the primary form of technology transfer is through human movement or interaction.

The individual plays a critical role in technology transfer as well as in the creation and modification of knowledge. This is especially true for the researcher. Each researcher is bound to some degree by the state of the art in his or her specific field or specialization. This can shape the innovation process, particularly because much innovation in the private sector does not take place at the research frontier but rather happens along the border of different fields. For example, the Human Genome Project, a massive multinational research program in the life sciences, is made possible only by the existence of very fast supercomputers, a technology that came out of a different field of informatics.

## Networks

In the literature about national systems of innovation, the idea of networks has become pervasive. The OECD (1992) has tried to look at networks as being agreements that exist somewhere between the marketplace and the hierarchy. Table 1 gives some of the key distinctions that exist between networks, markets and hierarchies.

As David Teece (1990) notes, the main reasons for participating in networks are the complementarities to be gained by pooling resources. By joining a network, firms and other organizations in a sense cease to exist independently; instead, they exist in relation to each other. The motivation for collaborating in these ways varies from firm to firm, since each has unique profiles and capabilities. Some firms seek to share risk, some seek increased scale, others look to diversify their technology base or transfer technology, while still others collaborate in order to access new markets.

The core benefits of firm collaboration and networking include:

- elimination of duplication
- ability to pursue a broader research program
- ability to take advantage of both scale and scope
- improvement of research management
- reduction of innovation time.

But perhaps the greatest benefits of the network idea are to be found at the local level. It is generally accepted that technology and investment not only are critical to both economic growth and job creation, but also are footloose; that is, unlike natural resources, they are not tied by geography but are able to locate wherever there is an attractive environment. This helps us to understand the mechanisms that have made regional examples of success possible. One need only think of the Silicon Valley in California, or Route 128 near Boston, in the United States.

Canada too has clusters of technology-intensive firms and institutions, for example, around Montreal, Ottawa, the Niagara peninsula, Edmonton and Vancouver. What these examples have in common is a success resulting from government–business collaboration (involving governments at every level), the presence of infrastructure, the availability of knowledge centres (such as universities and colleges), good skill sets in its local people, and patience coupled with vision.

Of course, not every local system of innovation specializes in the same areas. Some have strengths in biopharmaceuticals or microelectronics, while others might focus on transportation technologies. This is another important characteristic of this networked reality — what some call the clustering or swarming effect. Once local centres have chosen to compete in a small range of industries, technologies are bought (technological trajectories), firms, both competitors and suppliers, gather because of the availability of skills, etc., financial institutions learn to work with the peculiarities of the particular industries involved, and competitive reputation builds. This combination of factors creates an attractive environment for other firms, more investment, upgraded and extended infrastructure (funded both locally and from government sources), and so on. In other words, mechanisms and synergies develop.

## Concluding Remarks

The preceding discussion is conceptual, but it has considerable import or potential for reframing discussions about science, technology and innovation policy in Canada. Canada has a small, open economy. It has a limited market, limited resources available for research and development, a highly distributed population, and an industrial profile that still reflects both its national resource heritage and a heavy presence of foreign multinationals. Therefore, developing a critical mass in investment, technology and industry has long been problematic.

But we have an excellent string of universities across the country, a talented research base, a sophisticated consumer base, access and proximity to a large and highly developed market to the south, and recognized prowess in areas like telecommunications, remote sensing, multimedia technologies, transportation technologies and biomedical research. In other words, we have everything we need to compete internationally on the basis of our national system of innovation.

The keys to unleashing this potential will be found in our capacity to reframe the S&T debate. As important as they might be, we must not restrict our view of the new knowledge economy to the performance and funding of R&D with the vain hope that, if told to, our universities and government labs will do the kind of research that our firms need, and will pass on this new knowledge in a market-usable form. Innovation does not start in the labs and then spread evenly across the economy. Innovation and economic growth are systemic and depend equally on entrepreneurs, teachers, financiers, technicians, managers as well as researchers. We need to see innovation as a learning process in which we are all partners. This involves a major shift in the way in which the Government of Canada sees science, technology and innovation. But it also shares the responsibility (and opportunity) for local and regional growth with researchers, politicians and entrepreneurs in each locale. The OECD countries are waking up to the potential of national and local systems. We must not allow ourselves to fall behind. If we think that innovation and knowledge are too expensive, just think how expensive the consequences of ignorance and lethargy will be.

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# A Road Map through Rhetoric and Reality: Some Observations on 30 Years of Federal S&T Reviews

*by Paul Dufour**

Observers of the science policy debate in Canada over the past 30 years would not be faulted if they were to conclude (paraphrasing British wartime Prime Minister Churchill) that never has so much been written by so many with so little effect. The volume of published material could lead to this conclusion.

Of course, this is a cynical view. It overlooks an important result of the long-standing science policy debate in Canada on this important investment issue to galvanize the general public, the decision makers and the research community to view science and technology (S&T) issues as central to broad social and economic goals.[1] Science policy, like science itself, is undergoing rapid change, forcing the institutions of government to become flexible enough to deal effectively with both the support of science and innovation and the use of S&T for policy.

Change is the constant factor in these reviews of the government's approach to S&T management. As communications theorist Marshall McLuhan has argued:[2]

> ***The habit of always using the rear view mirror for navigation is now yielding because at jet speeds the rear view mirror has proved to be an unreliable device. But, also, at very high speeds, it becomes possible to recognize environments that were previously not noticeable.***

It is for this reason that it is important to step back and look schematically at what has transpired in the past 30 years as Canadian governments have examined the role of science in society and public policy for research. What has been explored and what has been learned? This essay builds on A Selected Bibliography of Major Federal S&T Policy Reports, which appeared in the *Resource Book for Science and Technology Consultations: Volume I,* and puts some of these source materials into a more nuanced focus on the forces that have shaped the Canadian debate.

## Some Early Inventories of the Science Policy Debate: 1960–77[3]

The Canadian debate on how S&T has been perceived within the public policy arena has an extensive history. It is fairly well documented, as the reader can glean from books on the history of Canadian science and engineering as well as on its leaders and heroes, along with various institutional histories of major organizations like the Geological Survey of Canada, the

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[1] One of the more insightful analyses of conditions shaping Canadian science policy and still quite accurate is that by Robert Gilpin, *Science Policy for What?: The Uniqueness of the Canadian Situation* (Ottawa: Science Council of Canada, 1971).

[2] Remarks made at an International Symposium on World Trade and Technology held at Gaithersburg, Maryland (Washington, D.C.: U.S. Bureau of Standards, 1966).

[3] For some of the earlier debates on science policy in Canada, see G. Bruce Doern, *Science and Politics in Canada* (Montreal: McGill-Queen's University Press, 1972); Raymond Duchesne, *La science et le pouvoir au Québec* (Québec: Éditeur officiel du Québec, 1978); F. R. Hayes, *The Chaining of Prometheus: Evolution of a Power Structure for Canadian Science* (Toronto: University of Toronto Press, 1973).

[4] For a smattering of such works, the reader could consult a work by Morris Zaslow, *Reading the Rocks: The Story of the Geological Survey of Canada* (Toronto: Macmillan, 1975) or one edited by Richard Jarrell and Yves Gingras, *Building Canadian Science: The Role of the National Research Council* (Ottawa: Canadian Science and Technology Historical Society, 1992). For more specific works, the journal of the history of Canadian science, technology and medicine, *Scientia Canadensis,* is a good source.

Central Experimental Farms, Atomic Energy of Canada Limited (AECL) and the National Research Council of Canada (NRC).[4]

But the deliberate discussion over how federal government S&T are to be funded and how their institutions are to be developed is of more recent vintage. As early as 1946, immediately following the Second World War, several scientific/industrial groups aggressively lobbied the government on the role of science in reconstruction. Underlying principles were enunciated that strike a resonance in today's debates. One such document argued:[5]

- Scientific research, because of its importance to economic and social progress, must be kept out of the realm of partisan politics.
- Its pursuit necessitates the highest degree of cooperation between business, government and the universities.
- Research is intensely individual, and depends upon good people. There is no such thing as "second best" in the field of research.
- Fundamental and applied research can no longer be entirely separated. The war showed the extent to which they have become linked.

This document also warned:

***Instead of conflict, there should be enthusiastic cooperation between business and government and the universities in making a simultaneous advance on a wide scientific front. Only in this way can we hope to harness all of our scientific resources to the task of meeting changed and changing world conditions.***

### Lamontagne Report

Prior to the mid-1960s, before science policy became popular and the Organisation for Economic Co-operation and Development (OECD) instituted its meeting of science ministers, science policy in Canada was largely a history of the NRC. The NRC had been science adviser, national academy, technology transfer agent, science library, granting council, training ground for Canadian researchers, and international standards body. It had been the creator or driving force behind many of Canada's premier research agencies, including the AECL, the Medical Research Council, the Defence Research Board (and latterly the Natural Sciences and Engineering Research Council and Canadian Space Agency).

Because of its legacy, the NRC became the focus of many of the federal government's reviews of S&T. A landmark study of the NRC's role and the evolution of science policy was the four-volume report of the Senate Special Committee on Science Policy titled *A Science Policy for Canada.* Popularly named after its chairperson, the economist Senator Maurice Lamontagne, the work spanned a decade from 1968 to 1977. While the Lamontagne report summarized hundreds of submissions and testimonials from the Canadian research community, it did not offer a complete answer to the problems afflicting Canadian science. Its major contribution was the authors' courage to question many of the dogmas surrounding the link between public policy and S&T.

While its impacts are still debated, more than anything else the Lamontagne report made transparent and certainly more democratic the public's knowledge of the science enterprise. Its recommendations led the scientific research community to become more accountable for its activities. As a result, Lamontagne and his colleagues created a debate in Canada about the appropriate role and nature of society's responsibility for fostering a creative economy. The scientific community recognized the need for directing its creative energies along lines that would benefit the nation, and also emphasized the need for balance that would not destroy creativity by overdirection.

This debate is still with us today. As *The Economist* argued in a 7 May 1994 editorial:

***The direction of research can change, sometimes for internal reasons . . . sometimes because of goings-on elsewhere. Governments can shape the flow without staunching it. But they run the risk of limiting inspiration and dampening enthusiasm: a risk practical men should beware.***

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[5] See "An Interim Memorandum on Scientific Research in Canada," Toronto, 1 October 1946.

Lamontagne's report cannot be easily summarized; its recommendations were numerous and are still quite topical. Among the suggestions were:

- a National Research Academy (this is the subject of a recent report from an independent panel to the federal government)
- a Ministry for Science (the idea was borrowed from the New Democratic Party, which argued for such a ministry in 1967)
- a Canadian Innovation Bank (which would provide risk capital for local entrepreneurial talent)
- a research and development (R&D) expenditure target that would reach 2.5 percent of gross domestic product by the year 1980 (the figure is 1.5 percent today)
- an increase in the proportion of industrial research in R&D expenditures to 60 percent by 1980 (industry performs about 54 percent today).

The Senate committee's output generated a considerable debate in Canada and elsewhere. Indeed, the OECD issued a major report on Canada's S&T system in 1969, just at the time the Lamontagne hearings were in full swing. All this focus on S&T engaged the attention of many in the scientific community, leading to the creation of a journal called *Science Forum* (no longer published).

According to a 1972 summary[6] of some of the work by the Lamontagne committee, the following themes emerged:

- Investment in scientific research must follow the pattern of national priorities and must give special importance to industrial research.
- There must be a more precise evaluation of scientific research so as to terminate what is no longer valid and shift investments to new priorities when these present themselves.
- A coherent organizational system must replace the conflicting pattern of responsibilities so that a dynamic, ongoing process can be achieved that will take account of both the needs of science and those arising from the changing priorities in national objectives.

This last point reiterated a recommendation for the introduction of new machinery for science policy at the federal level in 1963 in the report of the Royal Commission on Government Organization, popularly called the Glassco report after commission chairperson J. Grant Glassco, former president of Brazilian Traction, Light & Power Co. Ltd. Among the issues explored, the Glassco report[7] examined the organization of science in the Government of Canada. Commenting that "the failure to build on the basis of a cohesive program has not inhibited the spending of public money," the report offered some recommendations designed to strengthen the organization of science, including the establishment of a Science Secretariat within the Privy Council Office. This innovation also led to the creation in 1966 of a Science Council of Canada to provide independent advice. The Science Secretariat eventually became part of the Ministry of State for Science and Technology (MOSST) in 1971, and the Science Council continued to function as an arm's-length agency until its dissolution in 1992.

### The International Context for Science Planning

The early work of the Science Council of Canada produced a landmark study in 1968 called *Towards a National Science Policy for Canada* (Ottawa: Queen's Printer, 1968). This report outlined explicit goals for science policy and framed them within a broader context of social and economic strategy. The goals were:

- national prosperity
- physical and mental health and high life expectancy

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[6] Philippe Garigue, *Science Policy in Canada* (Montreal: The Private Planning Association of Canada, 1972).

[7] See especially Royal Commission on Government Organization, *Volume 4: Special Areas of Administration* (Ottawa: Queen's Printer, 1963).

- a high and rising standard of education readily available to all
- personal freedom, justice and security for all in a united Canada
- increasing availability of leisure and enhancement of opportunities for personal development
- world peace based on a fair distribution of the world's existing and potential wealth.

This period was also one where "mapping" of science and research capabilities was seen as important to the debate. In addition to its early reports on major programs such as space programs, water resources and the Intense Neutron Generator proposal, the Science Council of Canada began producing assessments of scientific disciplines in Canada in conjunction with scientific societies. This was an essential part of the data base and information required for understanding both the nature of science and its core capability in Canada. So too was the development of the science of science — indicators of the health of research — which had emerged as a *bona fide* activity in many countries.

It was also a time when governments around the world were exploring the emerging role of science in society, when university research was well funded and when science policy was little coordinated within the central machinery of government. The OECD began a rigorous examination of these issues and in 1969 published numerous inventories and assessments of the research systems in various countries, including Canada.

Probably the most cogent report to summarize the thinking of this early science policy period is found in the OECD's *Science Growth and Society: A New Perspective* published in 1971 and authored by a group of experts led by Harvey Brooks, the Dean of Engineering at Harvard University. This report captured much of the debate in that period over such issues as integration of science policies with economic and social policies, the role of multinational firms in technological progress, international aspects of environmental problems as well as science and development along with science policy and general planning. Many of the issues raised by the report dealt with S&T priority setting within government and how science policy can be used to serve national and international goals.[8]

## The 1977–84 Consolidation Period: Technology Emerges as a New Economic Currency[9]

When the Lamontagne Senate committee in 1977 produced its last volume, the Canadian science policy debate was fully joined. Scientific associations and industrial lobby groups picked up some of the issues respecting innovation and economic growth. Technology forecasting and technology assessment, which had emerged in the early 1970s, became popular decision-making tools within some industries and government agencies. The provincial governments also joined the fray with policies and new programs to stimulate and promote innovation and technological development. Quebec, which had instituted a Conseil de la science et de la technologie in 1972 to advise its government on S&T policy issues (the first province to create such a structure), also established its first in a series of programs for R&D tax incentives to augment industrial innovation by Quebec firms. Quebec produced a flurry of white papers and policy documents on the role of S&T in Quebec society. Other provincial governments had begun a dialogue with their science and engineering communities to look at ways to shape their respective innovation infrastructures.

Within the academic and business communities, a vigorous debate emerged over the reasons for Canadian underperformance

[8] For a discussion of the international debates on science policy during that period, see *International Science Policy: A compilation of papers prepared for the 12th meeting of the Panel on Science and Technology by the U.S. House of Representatives Committee on Science and Astronautics* (Washington, D.C.: U.S. Government Printing Office, 1971); see also the interesting paper on the Canadian debate in that volume by Senator Allister Grosart, "The Legislative Role in Science Policy."

[9] For a useful bibliography of articles, documents and books on technology policy in the 1963–83 period, see Gérard Boismenu and Graciela Ducatenzeiler, *Technologie et Politique au Canada: Bibliographie 1963–1983* (Montreal: Cahiers de l'ACFAS, 1984).

in industrial R&D and the need for improvement. This discussion was probably best represented in the writings of the Science Council and the Economic Council of Canada, in which the interventionist technological sovereignty arguments of the former were pitted against the free market ideology of the latter. In reality, much of this debate was about the appropriate role of government in supporting industrial innovation and providing a climate conducive to creative talent in a cold climate. Also prevalent was a debate between the Canadian science community and the government over the degree to which research could be directed.

Further debate during this period took place on the role of energy policy and technology especially with respect to nuclear futures, Canada's space program, science and development, foreign ownership and its impact on R&D performance, the development of science in the North, the introduction of information and telecommunications technology, and funding for university/research personnel. Also on the agenda was the emergence of the notion of Canada as a conserver society and an array of environmental issues.

### Science Policy and the Rise and Fusion of MOSST[10]

By 1977, the Ministry of State for Science and Technology (MOSST), which had been established to encourage the development and use of S&T in support of Canada's economic and social goals, was into its fourth minister (as of August 1994, Canada has had 20 ministers responsible for science since 1971). MOSST had been involved with a number of key elements of the government's portfolio approach to S&T. Among them were the development of a science policy framework to provide guidance on scientific activities to all departments and agencies in terms of science priorities and strategies, the development of annual science expenditure guidelines for use by government departments and agencies (in conjunction with Statistics Canada), and an annual assessment of accomplishments in federal government science activities, largely through its Main Estimates and annual reports to Parliament.

MOSST had developed the so-called make-or-buy policy in 1973 designed to increase the proportion of government R&D requirements contracted out to industry, a traditionally weak performer, rather than performed in-house. The government's contracting-out mechanism under this policy is still in place. While S&T had until then played a relatively small part in the decision-making frameworks of government, it gradually emerged as a central factor in economic growth and social change. The 1974 Speech from the Throne stated that MOSST's role needed to be strengthened to ensure more efficient use of human resources and scientific activities in pursuit of national goals. This led to a better definition of the roles of the NRC, Science Council and Defence Research Board, and ultimately to the establishment in 1978 of the Natural Sciences and Engineering Research Council and the Social Sciences and Humanities Research Council. The Speech from the Throne had also for the first time articulated the objectives of science policy as:

> ***the rational generation and acquisition of scientific knowledge and the planned use of science and technology in support of national goals.***

In 1978, the Minister of State for Science and Technology released a discussion paper and announced some measures to strengthen and encourage R&D in Canada. These included a new national priority of reaching a target of 1.5 percent of gross domestic product for R&D expenditures by 1983. This became an ongoing question at a time when money was still available, and when there existed the prevalent yet mistaken notion that R&D was the only input to innovation. Also announced were efforts to use federal government procurement to stimulate R&D, open federal laboratories to the private sector, increase funding for university research in areas of national concern, and develop Centres of Excellence on a regional basis.

[10] For an assessment of the role of Ministries of State and why MOSST had difficulty in having its analyses accepted and implemented by government departments, see Peter Aucoin and Richard French, *Knowledge, Power and Public Policy* (Ottawa: Science Council of Canada, 1974).

In 1981, MOSST announced an R&D Planning Framework to put more flesh on the 1978 measures. Targets were notionally assigned to each R&D-performing sector of the economy, and an attempt was made to assess progress toward these targets. This was followed with a May 1983 statement by the minister proclaiming A Technology Policy for Canada.[11] This action had been influenced in part by the establishment the previous year of a special working group of the Group of Seven (G-7) most advanced world economies, which includes Canada, on technological change and development at its first summit meeting, held in Versailles, France. It was also the first time that government policy in Canada explicitly recognized the importance of technology to economic growth and quality of life issues.

Released prior to a national electoral campaign, the 1983 statement had four broad objectives:

- strengthen the Canadian economy through creation, application and diffusion of state-of-the-art technologies
- make Canadians aware of the opportunities and problems that might arise from the process of technological change
- ensure that the benefits of technology development are shared equitably among all Canadians in every region
- encourage a social climate that places a premium on scientific and technological excellence, curiosity and innovation.

The report also identified how these objectives would be applied to the business, university, labour and government sectors, including the provinces. Among its policies, the government announced the establishment of a special subcommittee of the federal Cabinet designed to integrate critical technology development decisions in all policy areas and to increase the coordination of federal incentives for research and technology development.

The 1983 policy also announced a number of specific measures dealing with R&D tax incentives, new research facilities, greater outreach to small business through additional funding of NRC's Industrial Research Assistance Program (IRAP), increased funding to the granting councils, a fund to promote public awareness of S&T, and strategies to improve the position of strategic technologies in areas of biotechnology, communications and microelectronics. In November of that year, the government held the first major conference on prospects for technological change in Canada. Called the Canada Tomorrow Conference, the event brought together more than 700 participants to debate both the promise and pitfalls of technological change on Canadian society. It marked the beginning of a decade-long series of public consultations on S&T. The opening statement by the Prime Minister on the role of government in this enterprise is worth noting:[12]

> ***The government must be more than a patron of technological enterprise, more than a source of funding, for even more fundamental is the government's responsibility to help manage the impact of technological change, and to act as an honest broker between competing forces in the movement towards a technologically sophisticated society. . . . The government's preoccupation must be to ensure that the benefits of this revolution outweigh the costs.***

## National Consensus and Convergence of Policy Efforts: 1984–93

Following a change in federal administration in 1984, the S&T policy debate in Canada became much more attuned to economic imperatives and nation-building objectives. The new government's first term saw the launch of free trade negotiations, the introduction of a deficit reduction program, the results of the Royal Commission on the Economic Union and Development Prospects for Canada (the

[11] The first attempt at a technology policy statement had been published four years earlier by the Science Council of Canada, *Forging the Links: A Technology Policy for Canada* (Ottawa: Science Council of Canada, 1979).

[12] *Canada Tomorrow Conference, Proceedings*, November 6–9, 1983 (Ottawa: Supply and Services Canada, 1984), p. 8.

Macdonald commission), and considerable energy devoted to a national approach to S&T. In successive budgets and Speeches from the Throne, the government announced various measures to strengthen the S&T base in Canada.

The efforts of the government to make its public labs more relevant to the economy received a considerable boost from several reports. A discussion paper on *A Future for R&D in the Public Service?* (Ottawa: Professional Institute of the Public Service of Canada, 1983) had presaged the difficulties and stress affecting federal R&D. The report of the Task Force on Federal Policies and Programs for Technology Development chaired by Douglas Wright, President of the University of Waterloo (Ottawa: Supply and Services Canada, July 1984) and a report of the Senate Standing Committee on National Finance, *Federal Government Support for Technological Advancement: An Overview* (Ottawa: Senate, 1984) were two examples of key examinations of the government's approach to its own labs.

The Wright report assessed the effectiveness of government's industry support programs, the government's procurement of technology-intensive products and its support for university-industry linkages. It had a receptive audience for its argument that certain of the government's programs administered by the NRC should continue to be supported, but that others should be more responsive to the marketplace, with the suggestion that a model for government-owned, contractor-operated labs might be developed. Such an experiment has since been put in place at the Burlington Wastewater Technology Centre, for example.

The Senate finance committee report addressed several well-known deficiencies in Canada's innovation system. It recommended that grant and contribution programs to support R&D should be responsive to the needs of industry and the marketplace; that a re-examination of the rationale for the federal government's support of technology centres across the country should take into account the provincial initiatives already in place; and that the intramural R&D programs of federal departments and agencies should be reviewed to exclude from them any activities that could be done more appropriately in the private sector.

These reports were soon followed by a massive program review of government operations conducted by the parliamentary Task Force on Program Review under its chairperson, Deputy Prime Minister Erik Nielsen. Its 17th volume, *Economic Growth: Services and Subsidies to Business* (Ottawa: Supply and Services Canada, 1986) contained some of the same recommendations put forward by the Wright report respecting public labs.

### The National S&T Policy Saga

The nation-building exercise was kicked off by a federal-provincial meeting in Calgary of ministers responsible for S&T, which was reported in a February 1985 working paper by the MOSST minister titled *Science, Technology and Economic Development* (Calgary: Ministry of State for Science and Technology, 1985). In addition to a series of statistical profiles of Canada's S&T performance, the report brought forward a discussion of four familiar themes: increasing private sector investment in innovation, accelerating the rate of diffusion of technology, redefining the role of government R&D, and recognizing the importance of academic R&D.

A major national forum sponsored by the federal government and hosted by the Science Council of Canada took place in Winnipeg in June 1986. The opening speech was on "Science and Technology: Developing a New National Purpose for Canada for the 21st Century," in which the MOSST minister asked for views on how the federal S&T budget could be more effectively spent to forge better linkages between universities, research institutes, colleges, private sector firms, government labs, and schools.

The minister later asked the Science Council of Canada to undertake an evaluation of the effectiveness of public sector funding of R&D in Canada. Among other things, the Science Council's response to the minister concluded that direct transfers from the government to the business sector, excluding tax incentives, had played a minimal role in increasing industrial R&D in Canada.

On 4 March 1987, the Prime Minister delivered a major address on R&D at the University of Waterloo. The address was an open challenge to the private sector to increase its R&D efforts and to redouble efforts to transfer technology out of university and government labs into industry. He closed with an appeal to all stakeholders to understand how Canada's technology can strengthen national sovereignty and territorial integrity.[13]

A National Science and Technology Policy was signed in Vancouver on 12 March 1987 by the federal, provincial and territorial ministers responsible for S&T. This policy, the first of its kind in Canadian history, outlined six objectives:

- improving industrial innovation and technology diffusion
- developing strategic technologies
- ensuring the necessary pool of highly qualified people
- supporting basic and applied research and development
- dealing with the impact of technological change in society
- promoting a more science-oriented culture.

To implement these objectives, a Council of Science and Technology Ministers was established and an action plan was developed to push forward each of the areas identified in the national S&T policy. The federal response to this policy, *InnovAction: The Canadian Strategy for Science and Technology* (Ottawa: Ministry of State, Science and Technology Canada, 1987), was announced two weeks after the Vancouver meeting. This five-track strategy put forward $1.5 billion in support of a federal microelectronics strategy, a new technology centres policy for the management of key federal labs and external technology centres aimed at promoting technology diffusion, funding for the Networks of Centres of Excellence, a Canada Scholarship Program for undergraduate students, new funding for unsolicited proposals program for government procurement, increased funds for IRAP, and an increase to the matching policy funding for university research.

A Decision Framework for S&T in the Government's Management of S&T Activities was also announced at this time. Prepared by MOSST at the request of the Prime Minister, the Decision Framework was designed to assist science-based departments and agencies to manage their S&T activities, and was intended for use as the basis for an annual overview of federal S&T strategic directions for Cabinet and the National Advisory Board for Science and Technology (NABST). It was related to three major purposes: economic and regional development, support of government missions, and advancement of knowledge and the supply of high-quality personnel. Its expectations were for better-informed government decisions in matters of S&T, improved coordination of federal S&T, stronger S&T activity by the private sector, and a flexible tool for federal S&T program managers to make their programs more relevant.

In November 1987, the Council of Science and Technology Ministers presented a *Discussion Paper on Canada's Research and Development Effort* to the Annual Conference of First Ministers held in Toronto. The discussion paper suggested a number of steps that First Ministers could take to improve the situation, such as consideration of a concept of a national Network of Centres of Excellence and development of R&D priorities within industry sector by sector.

In January 1988, a National Conference on Technology and Innovation was hosted by the Prime Minister in Toronto. Bringing together Canada's leading industrialists, decision makers, financiers and academic representatives, the conference was followed quickly by a series of five regional conferences across the country to develop an action plan on key issues affecting Canada's innovation. The result was a series of mission statements put forward to challenge the private sector in matters of leadership, finance, the workplace, education and training, and public awareness.

[13] The National Advisory Board for Science and Technology (NABST) chaired by the Prime Minister to give him guidance on key S&T policy issues had been previously announced; see the essay on the National Advisory Board for Science and Technology beginning on page 67 in this volume.

Throughout this period, federal investment in S&T was strengthened in a number of ways, including support for the Canadian Institute for Advanced Research, participation in international science programs and the establishment of funds to support international linkages, notably in Japan and Europe; support for specific federal-provincial S&T subagreements, especially with Quebec, British Columbia and New Brunswick; the creation of the Canadian Space Agency, and the first long-term space program, including approval of RADARSAT; improvements to the tax environment for R&D; and funding for several new institutes of technology development.

The House of Commons Standing Committee on Industry, Science and Technology, Regional and Northern Development examined several specific issues on the S&T policy front, including the space program and the future direction of IRAP. Its omnibus report, *Canada Must Compete* (Ottawa: House of Commons, 1990), attempted to summarize all that was deficient with respect to support for R&D and innovation in Canada.

Among its 31 recommendations, the report resurrected the idea that Canada's target for gross expenditure on research and development (GERD) should be 1.9 percent of gross domestic product by the year 2000. It urged adoption of a federal government five-year science expenditure plan, expansion of the Networks of Centres of Excellence program, establishment of a secretariat within the Privy Council Office to coordinate federal science policy and related resource allocation across departments, development of scientific and technical skills within the labour force, and strengthening and broadening of the IRAP network, especially in the North. The *Government Response to Canada Must Compete* (Ottawa: House of Commons, May 1991) contained detailed replies to each of the recommendations.

### Provincial Efforts

Meanwhile, provincial governments continued considerable experimentation in support of industrial R&D and innovation. New policy structures were created, including new ministries responsible for technology and research as well as advisory structures for S&T. For example, British Columbia's S&T policy, announced in 1987, served to guide public policy for investments in S&T. Several provinces, including British Columbia, Quebec and Ontario, established wholly dedicated technology funds. Others increased the use of their provincial research organizations to serve the needs of small business development and technology diffusion.

The OECD published a report on *Innovation Policy: Western Provinces of Canada* (Paris: OECD, 1988), which advocated a stronger innovation culture in the provinces, giving particular attention to the need to diversify traditional natural resource-based economies.[14]

In 1989, all of the science policy advisory mechanisms within the federal and provincial governments came together under the National Forum of Science and Technology Advisory Councils. Four meetings have been held so far, each hosted by a different province and dealing with a different theme of S&T policy. The recommendations have covered a broad spectrum of public policy concerns affecting the development of innovation in Canada.

### Competitiveness, This Time with Feeling

The competitiveness debate also received considerable play in the 1989–93 period.[15] Among these were several reports by NABST, the Economic Council of Canada, the Science Council of Canada, and industrial associations such as the Canadian Advanced Technology Association, the Canadian Chamber of Commerce and the Canadian Manufacturers' Association. The Royal Society of Canada

[14] See Paul Dufour and John de la Mothe, eds., *Science and Technology in Canada* (Harlow, U.K.: Longman, 1993), chapter 3.

[15] For a digest of some of these studies, see Industry, Science and Technology Canada, *An Overview of Selected Studies on Canada's Prosperity and Competitiveness* (Ottawa: Supply and Services Canada, 1992).

also attempted to play a stronger role in the national S&T debate with reports on public awareness of science, the increased role for women in science and engineering and the status and opportunities for Canadian science in selected fields of research such as materials and molecular biology.

A major report on Canada's competitiveness, sponsored by both the federal government and the Business Council on National Issues, was written by Michael Porter of Harvard University, titled *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Monitor, 1991). The Porter report reviewed 25 specific industry sectors[16] in relation to education and training, S&T, environmental and other regulatory policies, procurement and competition policy. Porter recommended that Canadian firms should improve their competitive edge by redefining their relationship with governments, especially in cooperating with the federal government to make publicly sponsored R&D, training and education more commercially relevant. Porter also challenged the government to rely on incentives instead of grants and to improve intergovernment financial policy coordination.

Triggered by the NABST competitiveness statement of 1991, which highlighted the serious problems facing the country in its competitiveness, the federal government launched a major national consultation on the country's competitiveness in October 1991 in partnership with the private sector. Known as the Prosperity Initiative, it was designed to produce a plan of action for securing Canada's future economic and social well-being. Co-chaired by Marie-Josée Drouin, Executive Director, Hudson Institute of Canada, Montreal, and David R. McCamus, Chairman of the Board, Xerox Canada Ltd., Toronto, the 20-member Steering Group on Prosperity produced a 54-recommendation action plan for Canada's prosperity called *Inventing Our Future: An Action Plan for Canada's Prosperity* (Ottawa: Supply and Services Canada, 1992).

Within the context of this exercise, a Task Force on Challenges in Science, Technology and Related Skills, co-chaired by Janet Halliwell, Chair, Nova Scotia Council on Higher Education, Ottawa, and Francesco Bellini, President and CEO, BioChem Pharma Inc., Montreal, was asked to put forward a framework of action outlining how Canada can best benefit from science, technology and engineering. The Task Force report, *Prosperity Through Innovation* (Ottawa: Conference Board of Canada, 1992), reviewed six major themes of innovation: creating advantage with people, financing innovation, globalization, science and engineering infrastructure, and sustainable development. The Task Force recommendations were directed at all stakeholders, including governments, educational institutions and the private sector. Among the more novel recommendations was a Competitiveness Council to provide leadership in matters of the economy and society, and a Technology Change Centre to analyze international S&T linkages, predict emerging trends in technology and assess the influence of new technologies on the Canadian quality of life.

All of this was taking place while governments around the world were re-examining how technical change and innovation affected economic growth and quality of life, and how public policy can best be used to ensure that innovation and technology respond to domestic needs and global concerns. The OECD was engaged in a round of workshops and analyses that led to the Technology Economy Program in 1989–91.[17] This exercise represents as good a synthesis of the directions for technology policy and all its facets as can be found anywhere else. Indeed, the report is just as much a landmark study as the Brooks report of 1971 referred to earlier.

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16 Sector-specific analysis had been applied previously in the Science Council's studies of 15 industry sectors, and was also taken up by the Conseil de la science et de la technologie in a large-scale analysis of Quebec's industrial/technology clusters in 1992–93.

17 See *Technology and the Global Economy: Summary of Discussions*, An International Policy Conference held 3–6 February 1991 in Montreal (Paris: OECD, 1991).

In Canada, the Canadian Institute for Advanced Research began a major international research program on economic growth and public policy, with technology and innovation at the core of the study. In the United States, numerous studies by institutions such as the Office of Technology Assessment, the Competitiveness Policy Council and the Carnegie Commission on Science, Technology and Government provided candid assessments of the growing importance of technology to the central functions of governance. The Asia-Pacific Economic Conference launched a working group on S&T to explore how scientific research can be used to promote regional cooperation and economic/trade objectives. The Carnegie commission launched an informal club of G-7 science ministers to meet biannually to discuss issues of concern and converging policy approaches to technology and research support. The OECD established a Megascience Forum for governments and their respective science communities to discuss plans for cooperation and creation of big science projects. The questions of the impact of technology on employment emerged front and centre as major policy concerns of all governments. And the question of public attitudes to S&T also received considerable play in the policy agenda.

In all of these areas, the S&T policy debate has shifted from a somewhat marginal role to a central one in national economic and social agendas. National systems of innovation have replaced the traditional S&T policy vocabulary. Considerable attention is now being paid to strategic partnerships, benchmarking, research output indicators, and priority setting as science and research enter a steady-state phase. The emphasis on applied results from the fruits of research is growing, and efforts are under way to direct publicly funded research to commercially applicable products and processes. New institutions have been established to address future trends in industrial technology, forecasting of critical technologies, and improved advice to the highest levels of government.

## From Lamontagne to Prosperity: Where Now?

The long series of debates and reports on science policy (now innovation policy) in Canada has produced numerous recommendations on how to improve economic competitiveness and quality of life. Some of these reports have had considerable impact and success, others less so. It is difficult in many instances to establish cause and effect. Was the introduction of special R&D tax incentives in 1978 the cause of the relatively rapid increase in industrial R&D research in Canada after 1978? Are Canadians to be satisfied with achieving the target of 1.5 percent of gross expenditures on R&D as a proportion of gross domestic product in 1993, almost 15 years after such a target had been postulated by Lamontagne? To what extent did numerous recommendations on improving the climate for pharmaceutical research in this country lead to an increased investment portfolio by large pharmaceutical firms in Canada? What were the factors/recommendations that led to the fusion of the MOSST into a new department of Industry, Science and Technology Canada and then to a department of Industry Canada?

The nature of the public policy process is such that in many instances the **process** undertaken is just as critical as if not more than the product. Indeed, in a number of cases, forthcoming recommendations are implemented before the final product is made public. Further, repetition can help. In many of the reviews noted above, similar recommendations have been made. But conditions must be right to achieve implementation. Thus, timing, leadership and personal commitment can often make the difference between the adoption of a course of action and its relegation to the dustbin of history. At times, public policy efforts in other countries can propel Canadian action. Because ideas know no boundaries, it is critical to maintain a watching brief on developments around the world. Occasionally, what an international body or group says about

Canadian innovation efforts can have more impact than what is said at the domestic level. Similarly, powerful new strategies in other nations that change the context of international competition can have major impacts upon the kinds of options that should be explored in Canada.

Rarely have these examinations led to radical change. Much of what has transpired has been incremental, but it has led to gradual transformation of how research and innovation in this country are managed and performed. Some of the change has been institutional, with experimentation in how to change behaviour among the government, industrial and scientific communities. Other advancements have come about because of the commitment of champions for change. The common threads to all of these reports reflect the specific history, economic structure, research infrastructure and institutional developments unique to Canada. Because of this, it is no surprise that similar themes have emerged in the Canadian S&T policy debate. Differences in approach have arisen as a result of urgency, fiscal constraint considerations, new forces in the globalization of knowledge, and the ability of stakeholders to marshall persuasive arguments for change.

In June 1993, NABST issued the first of two reports calling for a coherent approach to setting S&T priorities horizontally across the federal government.

With the February 1994 federal budget, the government has announced its intention to conduct a review of federal S&T and to move toward the development of a national S&T strategy. The June discussion paper *Building a Federal Science and Technology Strategy*, companion piece to these Resource Book volumes, places research and innovation at the centre of the public policy debate over how to create jobs and how to allow the integration of economic with environmental goals to enhance the quality of life for all Canadians. These questions are not new; they have been with us all along. However, the context both nationally and internationally has changed, as has the pace with which S&T now imbed themselves in our everyday lives. The attention government now is placing on these investments requires that decisions to address serious social, economic and environmental problems and ability to ensure innovation and knowledge are well grounded in sound policy advice. As one observer has noted:[18]

> ***Science and technology were once the condiments of our civilization. . . . More recently they have been regarded as vitamins, tiny quantities of which could prevent stunted growth and enable us to absorb our industrial nourishment. Now they must be reckoned as the very meat and potatoes of our economy.***

[18] Derek J. deSolla Price, as cited in *Reaching for Tomorrow: Science and Technology Policy in Canada 1991* (Ottawa: Science Council of Canada, 1992), p. 68.

# "Big Science" in Canada

*by Pardeep Ahluwalia**

"Big science"[1] has become synonymous with expensive science. The term therefore often has negative connotations, both in the scientific community and with the public. Nevertheless, it is a useful one when discussing a means of conducting scientific research.

Big science is reliant either on large facilities, which are expensive to build and operate, or on large groups of people working toward a common scientific goal, with all the related costs of significant personnel and operating budgets. Some disciplines, such as particle physics, require both.

There is no conflict between "big science" and "small science." Rather, one is an extension of the other, with the various activities carried out to different degrees. Both kinds of science aim to advance knowledge. In most if not all cases, the move to big science methods results from technical necessity. It is not possible to explore the fine structure of matter at the molecular, atomic or subatomic level without neutron beams, synchrotron sources and particle accelerators. The study of the universe could not be undertaken without astronomical observatories. Physical examination of the Canadian continental crust can be achieved only through the efforts of large groups of scientists working together. Efforts to map the human genome require the resources of biomolecular scientists from around the globe devoted to a single problem. The study of systematic genetics, which relies on statistically elusive results, can work only through extensive, focused effort.

These are some examples of the types of activity under the general heading of big science. A more detailed list of Canadian activities in big science is provided in Table 1. In many cases, the scientists working in these research areas consider themselves to be doing small science. But the approach required, either in using large facilities or a big coordinated group of researchers, means that they are in fact involved in big science.

Big science is increasingly international because large facilities are becoming too expensive for most countries to build and operate on their own, or because the scale of the problem requires a concerted effort from researchers around the world. Sometimes, big science may be the only way to make a quantum jump in knowledge (e.g. the Large Hadron Collider or the Sudbury Nutrino Observatory). By participating in international big science projects, Canadian scientists can conduct research at the leading edge in various scientific areas at a fraction of the project's total cost. At the same time, they have access to the full intellectual and economic benefits of the project, as the following examples show.

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[1] The term "big science" denotes both big science and big engineering. Projects have the advancement of knowledge as their main focus, rather than the advancing of economic, industrial or defence objectives.

In "small science," an individual conceives of and carries out a scientific program, or directs a small group or laboratory in defining and executing a project, with the aid of modest apparatus.

The James Clerk Maxwell Telescope in Hawaii is a joint project of Canada, the U.K. and the Netherlands. The Canadian contribution to this world-class radiotelescope is $1 million per year, or 25 percent of the annual $4-million budget for the facility. For this contribution, Canadian scientists are guaranteed 25 percent of the observing time of the telescope, and have full access to all results obtained by other partners. In addition, this partnership gives Canada access to all new technologies developed for the telescope.

The Ocean Drilling Program is a major international project studying the makeup of the earth's crust under the ocean floors. The Canadian contribution of about $1.3 million toward the project's annual $42-million budget gives Canadian researchers full access to all aspects of the project. Due to Canadian involvement, three sites in Canadian waters have been examined, providing information of commercial and scientific interest about Canada's offshore resources.

## Definition

Building from a report of the National Advisory Board on Science and Technology (NABST),[2] the following general definition for big science was developed by the Natural Sciences and Engineering Research Council (NSERC).[3]

The primary goal of big science and engineering is the advancement of knowledge. Specifically, it:

- involves research in basic and/or applied science and/or engineering as its basic goal
- employs a formal organizational structure to facilitate the research of one or more teams of scientists, engineers and supporting technicians

Table 1 — Big Science and Technology Facilities and Programs (actual or projected)

| | Status | | Type of program | | Canadian role | |
|---|---|---|---|---|---|---|
| Facility/program | Existing and/or approved | Proposed | Large facility | Distributed program | Lead nation | Partner |
| ***Astronomy and Solar System Exploration*** | | | | | | |
| Optical Telescopes | | | | | | |
| • Canada-France-Hawaii Telescope | ● | | ● | | | ● |
| • Dominion Astrophysical Observatory | ● | | ● | | ● | |
| • Gemini Twin 8m Telescopes | ● | | ● | | | ● |
| Radiotelescopes | | | | | | |
| • James Clerk Maxwell Radio Telescope | ● | | ● | | | ● |
| • Dominion Radio Astrophysical Observatory | ● | | ● | | ● | |
| ***Earth Sciences and Oceanography*** | | | | | | |
| Solid Earth Sciences | | | | | | |
| • Lithoprobe | ● | | | ● | ● | |
| Oceanography | | | | | | |
| • Ocean Drilling Program | ● | | | ● | | ● |
| ***Fusion*** | | | | | | |
| • Tokamak de Varennes | ● | | ● | | ● | |
| • International Thermonuclear Experimental Reactor (ITER) | | ● | ● | | | ● |
| ***Life Sciences*** | | | | | | |
| • Human Genome Project | ● | | | ● | | ● |
| ***Global Change*** | | | | | | |
| • Boreal Ecosystem Atmosphere Study (BOREAS) | ● | | | ● | ● | ● |
| • Climate Modelling | ● | | | ● | ● | ● |
| • Global Energy and Water Cycle Experiment (GEWEX) | ● | | | ● | ● | ● |
| • Joint Global Ocean Flux Study (JGOFS) | ● | | | ● | ● | ● |
| • Northern Biosphere Observation and Modelling Experiment (NBIOME) | ● | | | ● | ● | ● |
| • World Ocean Circulation Experiment (WOCE) | ● | | | ● | ● | ● |
| ***Materials Research*** | | | | | | |
| • NRU Reactor at AECL-CRNL | ● | | ● | | ● | |
| • Canadian Irradiation Research Facility | | ● | ● | | ● | |
| • Canadian Synchrotron Facility | | ● | ● | | ● | |
| ***Subatomic Physics*** | | | | | | |
| • Tri-University Meson Factory (TRIUMF) | ● | | ● | | ● | |
| • Tandem Accelerator-Super Conducting Cyclotron (TASCC) | ● | | ● | | ● | |
| • Sudbury Neutrino Observatory (SNO) | ● | | ● | | ● | |
| • Large Hadron Collider (LHC) at CERN | | ● | ● | | | ● |
| • ATLAS detector at LHC | | ● | ● | | | ● |
| ***Space*** | | | | | | |
| • Space Station | ● | | ● | | | ● |
| • Radarsat | ● | | ● | | ● | |

[2] National Advisory Board on Science and Technology, "Report of the National Advisory Board on Science and Technology: Big Science Committee," Ottawa: 1989.

[3] Natural Sciences and Engineering Research Council of Canada, "Big Science and Engineering Research: A Position Statement," Ottawa, September 1991.

- is either carried on with dedicated, single-purpose equipment and facilities, or involves a concerted national or international project composed of numerous but coordinated subprojects
- is a research project or program that is too costly for federal agencies or departments to fund within their normal budgetary resources without serious distortion of their activities.

As big science projects become increasingly global in scope, countries have recognized the need for greater international cooperation and collaboration. In recognition of this need, the OECD has established a working group to examine mechanisms for ensuring increased cooperation in big science, in the expectation that the resources available internationally for support of big science can be used to their maximum advantage. At its first meeting in June 1992, this working group, called the Megascience Forum, adopted the following modification of the NSERC statement as a working definition of big science:

> ***Big science includes single-purpose facilities and large, complex research programs requiring international coordination that have the advancement of knowledge as their primary goal, and that employ formal management structures to coordinate the research activities.***

Projects related directly either to military issues or to the commercialization of products or processes were explicitly excluded by the OECD Megascience Forum.

# Human Resources for Science and Technology

*by Elinor Bradley**

In a knowledge-based economy, a nation's ability to generate new ideas and innovations, to improve productivity and international competitiveness and to adapt to technological change is dependent upon its stock of scientific and technological knowledge. This stock of knowledge is part of the human capital of the scientists, engineers and technicians employed in the country. Since Canada's economic future depends on the knowledge and skills of professionals in science and technology (S&T), it is important that the supply meets the demand both now and in the future.

Supply and demand forecasting is, however, difficult and rarely completely accurate.[1] Imbalances may and often do occur. Information on the current composition and deployment of scientists, engineers and technologists is an essential part of understanding supply and demand dynamics and is a necessary part of S&T policy making. This article provides information on some of the characteristics of the stock of scientists, engineers and technologists and indicators of their deployment for 1971, 1981 and 1991. It also raises some questions for further analysis.

Scientific and technological personnel may be defined in terms of educational credentials or of occupations. The occupational definition has been used for this report and the selected occupations assigned to the two fields below:

**Natural Sciences and Engineering**

- Physical scientists
- Life scientists
- Mathematicians, statisticians and systems analysts
- Architects and engineers
- Architectural, engineering and related technologists and technicians

**Social Sciences**

- Social scientists
- Social workers and related occupations
- Librarians, museum and archival scientists
- Other occupations in social sciences and related fields

The data forming the basis of this report are taken from the 1971, 1981 and 1991 Censuses of Population.

## Characteristics of the Stock of Scientists and Technologists

Between 1971 and 1991, the stock[2] of scientists and technologists nearly tripled, from roughly 292 000 to 814 000. However, as in most other occupations, the year-to-year growth in scientific and technological occupations was slower between 1981 and 1991 (4 percent) than during the previous decade (6.5 percent). Of these occupations in 1991, roughly 30 percent were related to the social sciences and humanities and 70 percent were in the natural sciences and engineering fields.

An important change in the composition of the scientific and technological work force has been the entry of an increasing number of women into the sciences and engineering

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[1] National Science Foundation, *Science and Engineering Indicators, 1993* (Washington, D.C., 1993), p. 74.

[2] The term stock here refers to the experienced labour force, that is, persons who were employed or unemployed in the week prior to the Census day, but who had worked since January of the Census year. The experienced labour force can be derived by deleting from the total labour force those unemployed persons 15 years of age or over who have never worked or who worked only prior to January of the Census year.

fields (Figure 1). Women in 1991 comprised 34 percent of the stock of scientists and technologists, up from 27 percent in 1981 and 15 percent in 1971. Despite this growth, women continued to be underrepresented in the natural sciences and engineering fields relative to all other professional occupations, and slightly overrepresented in the social sciences. In 1991, women comprised 20 percent of those in the natural sciences and engineering fields. In contrast, 68 percent of those in the social sciences fields in the same year were women.

Most growth in S&T occupations over the period occurred in the middle age group of those between 25 and 44 years. In 1971, 54 percent of all scientists and technologists were in this age group, increasing to 66 percent in 1991. This growth parallels the gain in the entire experienced labour force over the period, up from 42 percent in 1971 to 55 percent in 1991. In the latter year, the proportion of natural scientists in this age range was slightly higher (69 percent) than that for social scientists (66 percent).

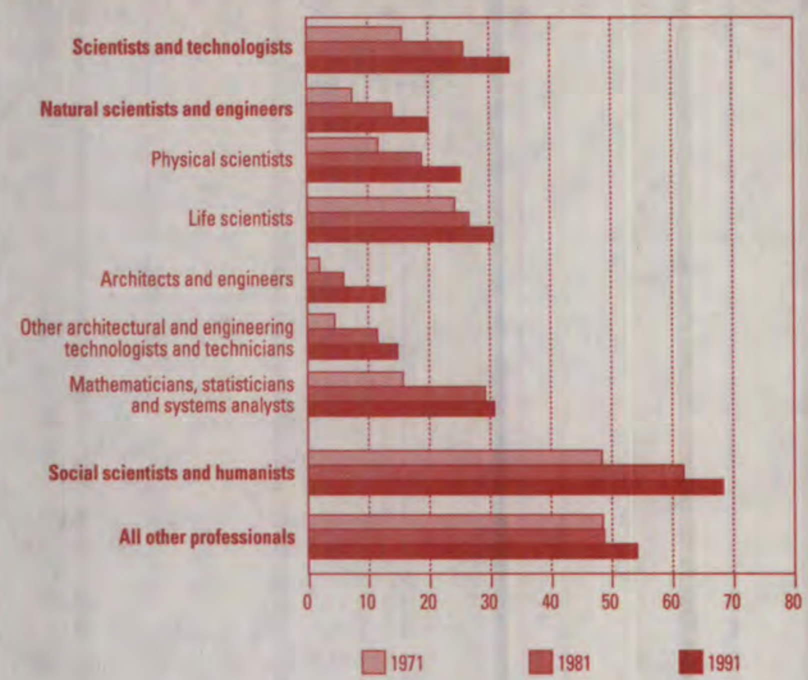
Scientists and technologists were more highly qualified in 1991 than they were in 1971: 46 percent held at least one university degree in 1991, up from 39 percent 20 years earlier.

## Deployment of Scientists, Engineers and Technologists

The most straightforward indicators of the demand for scientists, engineers and technologists are trends in the number employed or unemployed over time and in comparison with other occupations. The Canadian economy employed roughly 755 000 scientists and technologists in 1991, or 5.9 percent of all jobs in Canada, up from 4.7 percent in 1981 and 3.5 percent in 1971. Figure 2 shows that the year-to-year employment growth in the social sciences occupations as well as in natural sciences and engineering was greater than that for other professions[3] and for the total labour

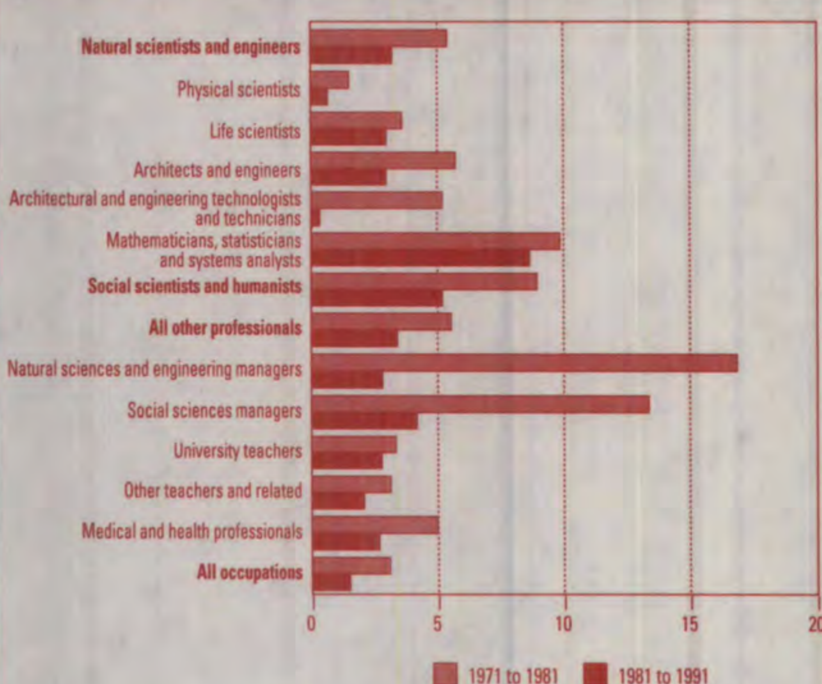
[3] Other professions include occupations in law and jurisprudence, teaching and related positions, medicine and health, managerial, administrative and related positions, and religious, artistic, literary, recreational and related occupations.

Figure 1 — Proportion of Women in Selected Occupations, 1971, 1981, 1991



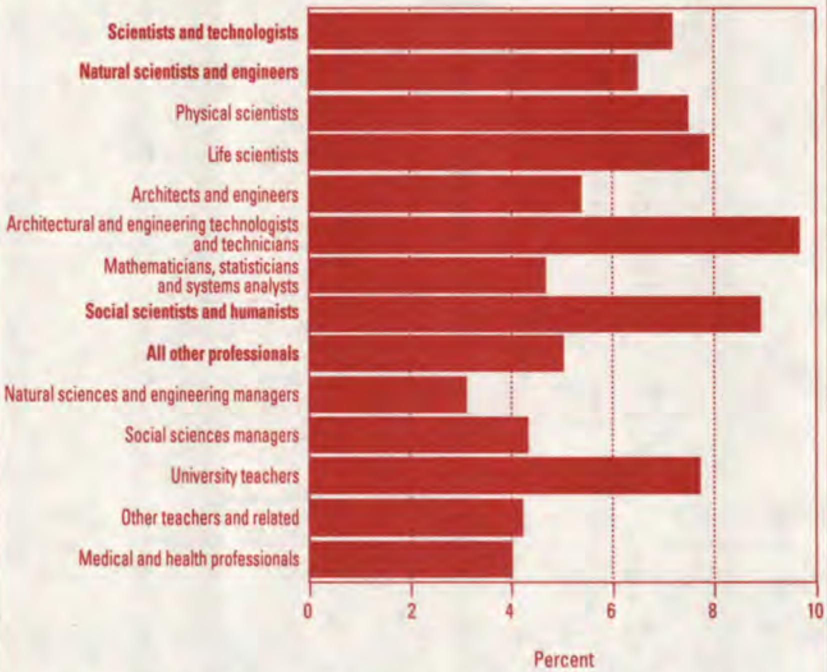

*Source:* Statistics Canada, 1971, 1981 and 1991 Censuses of Population.

Figure 2 — Average Annual Growth in Employment for Selected Occupations, 1971 to 1981 and 1981 to 1991




*Source:* Statistics Canada, 1971, 1981, and 1991 Censuses of Population.

Figure 3 — Unemployment Rates for Selected Occupations, 1991




*Source:* Statistics Canada, 1991 Census of Population.

force. Growth in the social sciences fields was mainly due to increases in social work occupations. In the natural sciences and engineering, growth was due to the rapidly expanding number of systems analysts, mathematicians and statisticians.

Figure 3 shows that at 7.2 percent, the unemployment rate for those in scientific and technological occupations in 1991 was not as high as that of the total labour force (10.4 percent), but was higher than that for other professionals (5 percent). Social scientists tended to experience unemployment more often than did natural scientists and engineers. Of those in the natural sciences and engineering occupations, mathematicians, statisticians and systems analysts as well as architects and engineers experienced lower unemployment than did physical scientists, life scientists or architectural and engineering technicians. However, unemployment rates for mathematicians, statisticians and systems analysts as well as for architects and engineers showed signs of creeping up, from 2.1 percent and 2.2 percent, respectively, in 1971, to 4.7 percent and 5.4 percent in 1991.

One of the main characteristics of the new knowledge economy is the increasing number of service sector jobs. The proportion of natural scientists and engineers working in this sector increased from 59 percent in 1971 to 70 percent in 1991. Of particular interest is the shift in the employment of architects and engineers as well as that of mathematicians, statisticians and systems analysts from the primary and manufacturing sectors to the service sector. In 1971, 41 percent of all architects and engineers were working in these two sectors, compared with only 30 percent in 1991. The percentage of mathematicians, statisticians and systems analysts in primary and manufacturing industries dropped from 32 percent to 15 percent over this same period.

Most natural scientists and engineers are concentrated in the business services area, which includes management and business consulting firms, computer services, engineering and scientific services and advertising services. As a result of this growth, natural scientists and engineers accounted for 12 percent of all those working in the business services sector, up from 8 percent in 1971. Service sector growth was primarily due to increased contracting out for new technical services and those previously performed in-house. Social scientists have traditionally been heavily concentrated (96 percent) in the service sector in the areas of education, health and public administration.

A useful indicator of the utilization of the scientific and technological work force is the degree to which personnel in these fields are engaged in full-time, full-year jobs. In 1990 (the first full year previous to the 1991 Census), 71 percent of the stock of natural scientists and engineers worked full time for the full year. This compares with 49 percent of the social scientists, and 53 percent of the total labour force.

Full-time, full-year workers in the natural sciences and engineering fields on average earned $43 765 in 1990. This compares with $34 205 for social scientists, and $45 560 for all other professionals. The average salary in 1990 for all workers was $33 715. The average salary for women who worked full-time and full-year was consistently lower than that for men. In the natural sciences and engineering occupations, women on average earned $34 970 in 1990, while men earned $45 660. Even in the social sciences fields where they are well represented, women earned less: $30 635 compared with $40 120 for men.

## University Teachers

Although not included in the definition of scientists and technologists shown above, university teachers, natural sciences and social sciences managers are components of the national pool of scientific and technological human resources. University teachers train the future supply of scientists and technologists as well as increase the stock of scientific knowledge.

Universities in 1991 employed 41 800 teachers, up from 31 600 in 1971. Figure 2 shows that the year-to-year growth in university teaching jobs was lower than that for natural and social scientists. The unemployment rate for university teachers has increased from 5.4 percent in 1971 to 7.7 percent in 1991.

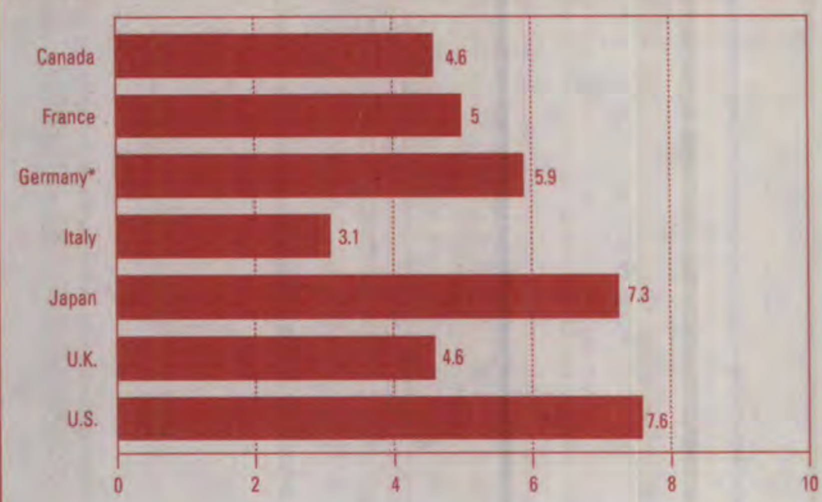
## Scientific and Technological Managers

The number of employed managers in the natural sciences and engineering grew from 2 500 in 1971 to 15 845 in 1991, possibly as a result of the increasing number of scientific and technological jobs. Social sciences managers increased in number from 2 000 to 11 050 over this same period. Figure 2 shows that the year-to-year growth was considerably less during the decade following 1981. Unemployment rates in 1991 for natural and social sciences managers were very low: 3.1 percent and 4.3 percent, respectively.

## Research Scientists and Engineers

While the preceding data relate to the kind of work performed by scientists and technologists in engineering, life sciences and similar professional occupations, the following information on research scientists and engineers relates more to their duties in performing research

Figure 4 — Research Scientsts and Engineers per 1 000 Labour Force, 1989




* Before unification
*Source:* OECD, Main Science and Technology Indicators Data Base, December 1993.

and development (R&D). As shown in Figure 4, Canada had fewer full-time equivalent research scientists and engineers (RSEs) per thousand in the labour force than did almost all of our main competitors.

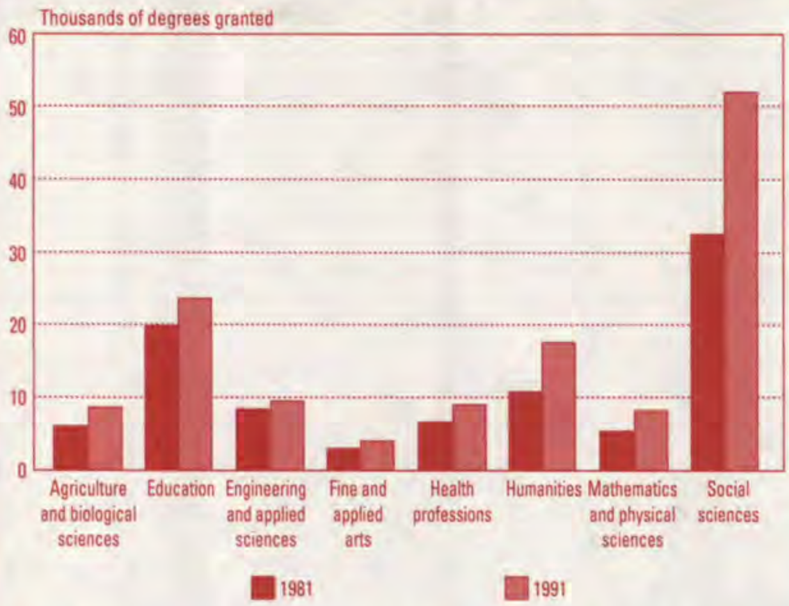
International comparisons can also be made with respect to the number of RSEs employed in businesses, higher education or governments. Canada is below the average for Group of Seven (G-7) most developed countries in the share of RSEs employed in business R&D (46 percent compared with 55 percent). On the other hand, Canada has one of the largest proportions employed in the higher education sector (41 percent compared with the G-7 average of 33 percent).

## The Supply of Scientists and Technologists

Graduates from universities and colleges are the largest and fastest-growing source of new scientific talent[4] (Figure 5). Between 1987 and 1991, Canadian universities awarded roughly 6 000 doctoral degrees, 18 000 masters' degrees

[4] Another important source of supply is immigration. See, for example, Natural Sciences and Engineering Research Council of Canada, *Highly Qualified Personnel* (Ottawa: NSERC, 1994), pp. 36-41.

Figure 5 — Fields of Study and University Degrees Granted in 1981 and 1991




*Source:* Statistics Canada, adapted from Education in Canada, 1986 and 1991–92.

and 110 000 bachelors' degrees in natural sciences and engineering. During this same period, colleges awarded 62 400 diplomas in engineering and applied sciences technologies and 14 000 diplomas in natural sciences and primary industries technologies.

The total number of natural sciences and engineering graduates appears to be far greater than what could be absorbed into the natural sciences occupations labour force. For example, in 1991 alone, the number of agricultural and biological degree recipients represented close to one quarter of the total number of those employed as life scientists in that year. However, over 40 percent of the doctoral and 33 percent of the master's degree recipients were foreign students, who may not be available to work in the Canadian labour market.

Figure 6 shows that close to 50 percent of all those with a postgraduate degree and 40 percent of those with an undergraduate degree in the natural sciences or engineering fields of study were working in an occupation related to their degree. This suggests that a degree in natural sciences and engineering is also accepted as a qualification for jobs in management and administration, teaching, and sales and services. Similar data for social scientists suggest that degree holders in these fields are even more dispersed among occupations.

## School-to-Work Transitions

**A** study[5] analyzing the school-to-work transition experience of a sample of 1982 bachelor's-level university graduates offers interesting insight into the demand for recent graduates. According to the study, engineering and mathematics/physical sciences graduates were most likely to choose the same program if given a second chance, followed by non-natural sciences and engineering graduates and agriculture/biosciences graduates. Social sciences graduates were least likely to give this approval. Forty percent of the least satisfied groups would have preferred another program.

Graduates in engineering and math/physical sciences had the closest match between education and job, followed by those in non-natural sciences and engineering as well as agriculture/biosciences fields. Social sciences graduates had the weakest matches. However, there is evidence of a gradual integration of graduates into the labour market over time as they moved increasingly into jobs related to their education.

Graduates in agriculture/biosciences consistently lagged behind other natural sciences and engineering as well as non-natural sciences and engineering graduates in satisfaction, matching of education to jobs, and earnings.

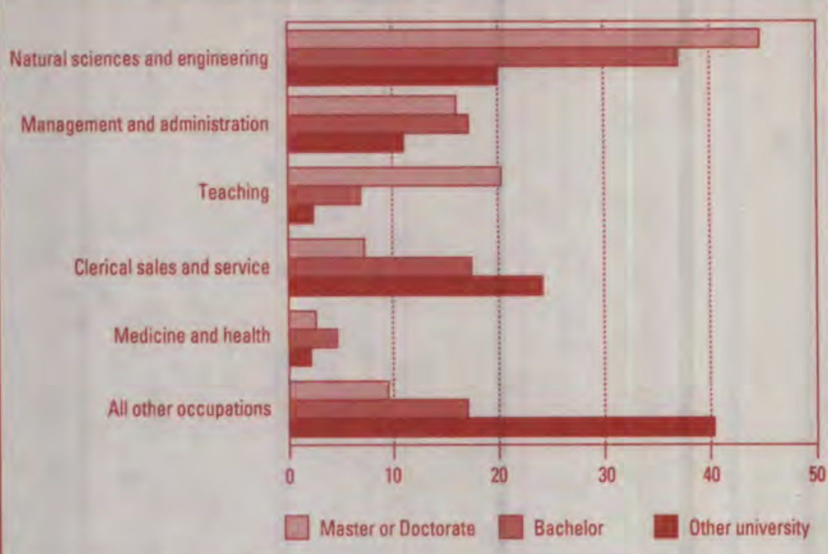
Engineering and math/physical sciences graduates earned significantly more (16 percent) than non-natural sciences and engineering graduates (11 percent) in 1984 (two years after graduation). However, men had lower mean earnings in 1987 (five years after graduation) than non-natural sciences and engineering students, while the advantage for women increased. Graduates in agriculture/biosciences earned consistently less (by about 10 percent) than their non-natural sciences

[5] Ross Finnie, "Steppin' Out: An analysis of the education experiences and early labour market outcomes of a panel of recent science and non-science university graduates," a report prepared for Industry Canada, Ottawa, July 1993.

and engineering counterparts. Most female natural sciences and engineering graduates tend to be in these low-paying fields. The overall gender earnings gap rose from 14 percent in 1984 to 24 percent in 1987, and was smallest for engineering and math/physical sciences graduates.

The relatively low wage premium for those who had studied engineering[6] and math/physical sciences five years after graduation may indicate that there is an adequate supply of engineers, although further research is needed. Interestingly, their premiums seemed highest for sales, clerical and business administration occupations, rather than natural sciences and engineering occupations. This suggests that engineering training may be in demand more for management and sales than for actual engineering jobs. However, the job match part of the study suggests graduates in engineering and math/physical sciences still have closer job matches than non-natural sciences and engineering graduates.

**Figure 6 — Percentage Distribution of Natural Science and Engineering Degree and Diploma Holders by Level and Occupation in 1991**




*Source:* Statistics Canada, 1991 Census of Population.

## Areas for Future Research

The foregoing data suggest that observed trends in the scientific and technological experienced labour force reflect not only the changing needs of the economy, but also the changing demographic characteristics of the entire labour force. Some important issues are also raised. For example, is the aging pattern of the scientific work force any different from that of the work force as a whole? If so, what are the causes and what are the potential downstream effects?

Does the increased proportion of advanced degree holders reflect the rising level of technical complexity of scientific and technological jobs, or mirror the tendency among baby-boomers to pursue higher education? What level of educational attainment will be required in the future? Is the earnings gap between men and women in these fields due to marriage and the presence of children, suggesting that male-female earnings differentials may be affected by differing family responsibilities, or are there other systemic causes?

Is the increased demand due to the increasing employment of technically trained personnel in non-technical occupations, or is this an indicator of oversupply? This leads to a need for understanding the role of technical education: Should it be only to train practitioners? Is it cost-effective for society to invest in technical training for non-technical occupations? What are the implications for the supply and demand of S&T personnel, particularly the supply side, on the educational system?

The degree to which supply-push or demand-pull affects the stock of scientists and technologists is difficult to determine. Perhaps the most difficult question to answer is: To what extent should S&T policies try to influence the supply or demand of the human S&T resource? These are issues for consultation and review between policy makers and stake holders as part of the national dialogue on science and technology issues.

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[6] For example, chartered accountants typically earn more than twice as much as professional engineers after ten years of practising. See Michael Porter, *Canada at the Crossroads: The Reality of a New Competitive Environment* (Ottawa: Monitor, 1991), pp. 176–77, for a discussion of the differences in salaries between chartered accountants and professional engineers.

# How Much Should Canada Spend on R&D?

*by Tammy Schulz**

Research and development (R&D) as an element of technological innovation has long been identified as playing an integral role in an industrialized economy's generation of wealth and the maintenance or improvement of living standards. The globalization of the world's economy and the rapid proliferation of new technologies in recent years have simply increased the emphasis on the performance of strategic research and has underscored the need for more scientific inquiry.

The most frequently used measure of science and technology (S&T) resource inputs into an economy is R&D expenditures. While there are many other measures of innovation, R&D expenditures, although an imperfect indicator, are used most often in public debates on the allocation of S&T resources because they are relatively easy to measure and there is an internationally recognized standard for collecting this data, the *Frascati Manual*.[1]

R&D expenditure levels, along with expenditures on S&T support services and training, are affected by government S&T policies and therefore attract considerable comment during national debates on the subject. In Canada, the Senate Special Committee on Science Policy, chaired by Maurice Lamontagne in 1972, acknowledged the importance of innovation in general, and R&D in particular, to national economic prosperity. Its report included the recommendation that 2.5 percent of gross domestic product (GDP) be spent on R&D annually so as to encourage the development of "a realistic and coherent [Canadian] science policy."[2] Despite government commitments to various R&D expenditure targets, there remains a controversy over whether it is appropriate for government to set a target for R&D expenditures and, if so, how the target should be determined.

## Where Canada Stands

In 1993, gross expenditures on R&D (GERD) in Canada were $10.6 billion — 1.5 percent of Canadian GDP. While Canada's allocation of resources to R&D is actually comparable with the middle rank of member countries of the Organisation for Economic Co-operation and Development (OECD), R&D performed in Canada remains consistently lower than that done in other Group of Seven (G-7) most developed nations (Table 1).

**Table 1 — Gross Expenditures on R&D, 1991**

| | | | R&D funding by source | | | |
|---|---|---|---|---|---|---|
| Country | GERD | GERD/GDP | All gov't | Gov't (civil)[1] | Domestic industry | Other private sector and foreign |
| | (US$ billion) | | (percentage of GDP) | | | |
| U.S. | 154.3 | 2.75 | 1.29 | 0.51 | 1.40 | 0.06 |
| Japan[2] | 67.3 | 2.87 | 0.46 | 0.43 | 2.22 | 0.19 |
| Germany | 35.6 | 2.66 | 0.97 | 0.86 | 1.61 | 0.08 |
| France | 25.0 | 2.42 | 1.18 | 0.74 | 1.03 | 0.21 |
| U.K. | 18.7 | 2.08 | 0.71 | 0.39 | 1.04 | 0.33 |
| Italy | 12.9 | 1.32 | 0.61 | 0.56 | 0.63 | 0.08 |
| Canada[3] | 7.8 | 1.50 | 0.66 | 0.61 | 0.61 | 0.23 |
| The Netherlands | 4.8 | 1.91 | 0.78 | 0.75 | 0.98 | 0.15 |
| Sweden | 4.2 | 2.90 | 1.10 | 0.80 | 1.74 | 0.06 |

[1] Industry Canada estimate based on government appropriations.
[2] Japanese data adjusted by OECD secretariat.
[3] The GERD/GDP ratio was adjusted by the OECD and therefore is slightly different from the one published by Statistics Canada.
*Source:* OECD, *Main Science and Technology Indicators* (Paris: OECD, May 1992).

* This analysis was prepared for the Secretariat for Science and Technology Review by Tammy Schulz, a junior economist at Industry Canada.

[1] *The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Experimental Development [Frascati Manual]* (Paris: Organisation for Economic Co-operation and Development, 1981).

[2] Senate, Special Committee on Science Policy, A *Science Policy for Canada; Vol. II, Targets and Strategies for the Seventies* (Ottawa: Queen's Printer, 1972) p. 599.

A comparison of Canadian R&D expenditures with R&D spending in other countries indicates that, among the major industrialized nations, R&D resource allocations tend to mirror government policy. Thus, the public sector in Canada places less emphasis on defence R&D spending, but the amount spent on civilian R&D is comparable with that found for similar projects in other countries. This poses the question: Is there an empirical relationship between size and/or the structure of the economy and the ratio of GERD to GDP?

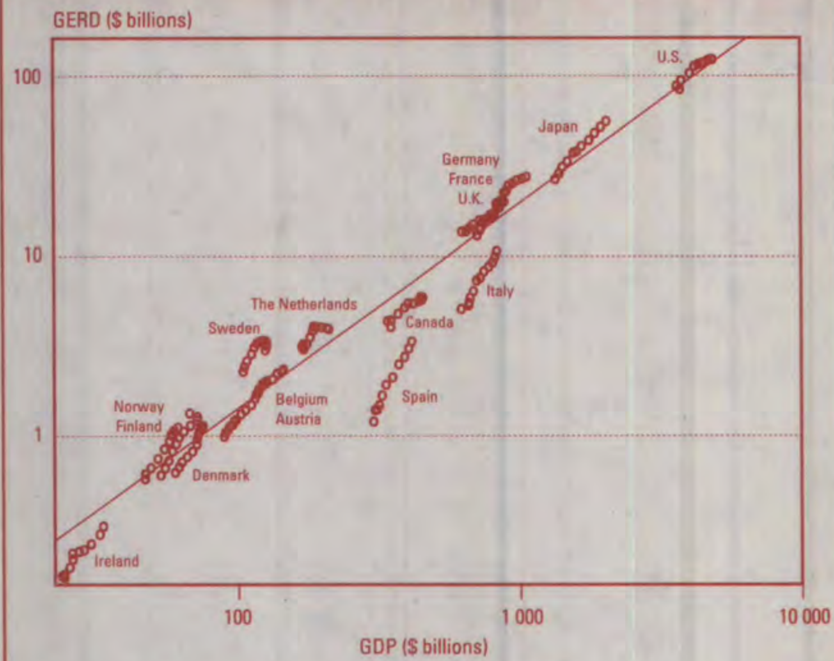
## GDP versus GERD

There is considerable evidence to suggest that technological innovation and R&D are in part a product of the synergistic effects of a large number of firms competing in the marketplace. From a policy-maker's perspective, it is important to know the degree to which scale effects operate and whether they are non-linear. In times of restraint, do relatively small increments in government R&D spending lead to improvements in productivity? Are R&D spending levels, particularly in the private sector, tied to the level of economic activity? Is it possible to test the proposition that R&D expenditures are a function of the size of the economy?

If the relationship between economic activity and innovation spending is linear, then free market economies should spend roughly the same proportion of their GDP on R&D, and the differences in absolute levels should be linearly related to differences in GDP. If the relationship is in fact not linear, but rather exponential and the exponent greater than one, then the larger economies should be in a position to devote increasing percentages of their GDP to R&D.[3]

Figure 1, which depicts Canada's R&D spending over the 11-year period from 1981 to 1991, reveals that Canada's GERD spending as a percentage of GDP is consistent with that of other developed countries, and that Canada's performance is comparable with that of the G-7 leaders in this area, the United States and Japan. The non-linear relationship between GERD and GDP suggests that, for policy discussions, Canadian R&D performance should not be compared directly with those of the other G-7 countries, but rather with the performance of a group of nations with similar GDPs.

Figure 1 — GDP versus GERD, 1981 to 1991




*Source:* Industry Canada estimates based on data supplied by OECD/STID.

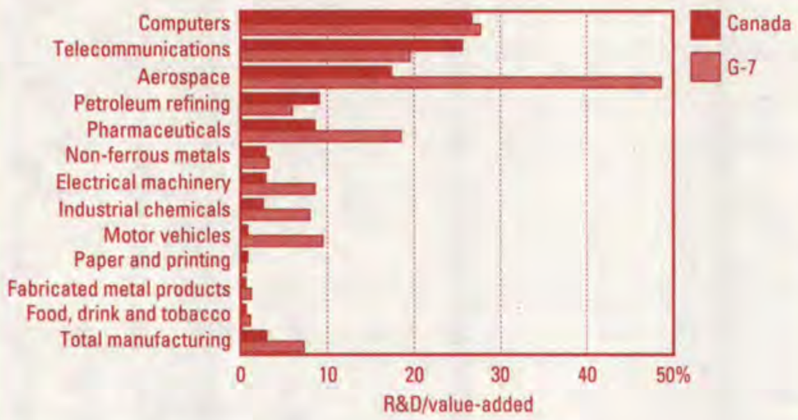
Holbrook (1991) argues that the relationship between GERD and GDP can be estimated by the equation:

$$GERD = k\,(GDP)^x$$

Using this equation and pooled data, over 11 years, for 16 OECD countries, it is possible through regression analysis to show that there is a statistically significant relationship between GERD and GDP ($\bar{r}^2 = 0.94$). The result is as shown in Figure 1. The exponent $x$ is 1.15, plus or minus 0.02, so the relationship is definitely exponential.

[3] J. A. D. Holbrook, "Scale Effects on R&D Expenditures," *Science and Public Policy*, 18 (2) [1991]: 259–62.

Figure 2 — Comparisons of Industrial R&D Spending, Canada versus G-7, 1989




*Source:* Industry Canada estimates based on data supplied by OECD/STID.

When Canada's GERD to GDP values are compared with those of other nations, it appears that the level of R&D funding in Canada falls considerably below the OECD average. However, while it has been suggested that Canada has undergone a period of sustained underinvestment, it has actually maintained a consistent rate of growth in GERD. More importantly, the growth in Canada's GERD appears to be consistent with its growth in GDP.

## Invisible Technology Transfers

Even though Canada's GERD lies on the lower spectrum of developed nations, many analysts argue that there is no need to change Canada's GERD spending. Kristian Palda[4] points out that, unlike other nations that spend a large portion of R&D resources on defence, Canada spends relatively little in this area and is therefore better able to allocate resources to other sectors. Palda also argues that Canada is the recipient of a significant amount of "invisible" technology from foreign-based multinationals — transfers that are not typically included in the calculation of GERD. Assuming an R&D intensity in high-tech sectors of 10 percent, and a high-tech trade deficit of $11 billion, "invisible" R&D — the R&D done elsewhere in developing the high-tech products, the cost of which is embedded in their selling price — could total $1.1 billion per year.

However, while there is a less than average allocation of R&D funding by the industrial sector, it is offset by funding coming into Canada from foreign sources for industrial R&D, primarily from multinational enterprises. Among the G-7 nations, Canada has the most generous R&D tax credit system, which may account for its significant foreign funding component. Direct foreign investment in R&D in 1993 totalled approximately $1 billion and has increased during the past 10 years, offsetting the R&D embedded in the deficit in the high-tech trade. The discrepancy between Canadian R&D and the "international average" has to be explained in some other way.[5]

## Canada's Low GERD — A Consequence of Structure?

Many explanations have been advanced for Canada's lower-than-average industrial R&D performance. The lack of a large defence component, inadequate government spending, foreign ownership and Canada's traditional reliance on resource-based industries have variously been cited as affecting the level of R&D investment in Canada.

While it is true that Canada places less emphasis on defence R&D than many other technologically advanced nations, both its total civilian public sector and performance expenditures are in line with those of other major industrial players. Changes in Canadian government spending on R&D are not a major factor in Canada's recent R&D performance. Furthermore, foreign ownership of industry appears to have actually increased the level of R&D performed in Canada through the inflow of R&D funding to the point where it is a major service industry in its own right.

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[4] Kristian S. Palda. *Industrial Innovation; Its Place in the Public Policy Agenda* (Vancouver: The Fraser Institute, 1984).

[5] See the article on Canada's Comparative Cost Advantage in Performing R&D, beginning on page 53 in this volume.

As Figure 2 illustrates, compared with the industrial sectors in other G-7 nations, the contributions of Canadian industry to national R&D spending are proportionally smaller than average. This is not surprising, however, considering the resource-based structure of the Canadian economy, because resource extraction industries typically spend a lower percentage of their sales on R&D than do manufacturing industries. The reasons for this lower level of R&D intensity are manifold, including the fact that many innovations in processes are brought to market by equipment suppliers, rather than the resource industries themselves. In the face of low-wage rate competitors, natural resource industries are always seeking ways to improve productivity.

Canada's historical reliance on natural resource-based industries, which are characterized internationally by relatively low investments in R&D, has meant that R&D has not grown as quickly in Canada as in other more diversified economies. From this perspective, low GERD figures in Canada are a direct reflection of the composition of our economy, not the lack of innovation or resourcefulness. Canadian technologically intensive enterprises appear to be competing well in international comparisons for many sectors. If this perspective is valid, an increase in the level of industrial R&D performed in Canada will only be achieved through diversification that results in a greater proportion of the economy being made up of those high value-added manufacturing and services where more R&D must be performed to maintain competitiveness.

## Policy Objectives

Domestic R&D expenditures grow exponentially as a nation's economic wealth increases: GERD is a function of GDP and is tied to a nation's level of economic activity. Thus, short of radical change, overall R&D expenditure levels are unlikely to change much. However, the influence of economic scale on total spending should not affect the policy debates surrounding the sectoral distribution of that R&D resource. Hence, one nation may choose to emphasize public sector spending, while another may choose to allocate its resources through the private sector. Once such choices are made, the very magnitude of these expenditures make them difficult to reorient quickly, as in the case of post-cold war defence R&D programs.

The empirical relationship between GDP and GERD suggests that there may be some underlying functional relationship between the two. Setting an unrealistically high R&D target could result in less than optimal allocation of scarce resources elsewhere in the economy since resources for other sectors would be diverted to the R&D effort. While governments and other R&D policy makers may influence the distribution of expenditures, for instance, through defence or tax policies, it remains unlikely that they can change the overall R&D spending levels to any significant degree. The most likely way significant increases in R&D funding will occur will be through economic growth and structural change.

# Does Foreign Ownership Affect R&D Performance?

*by Adam Holbrook and Robert Squires**

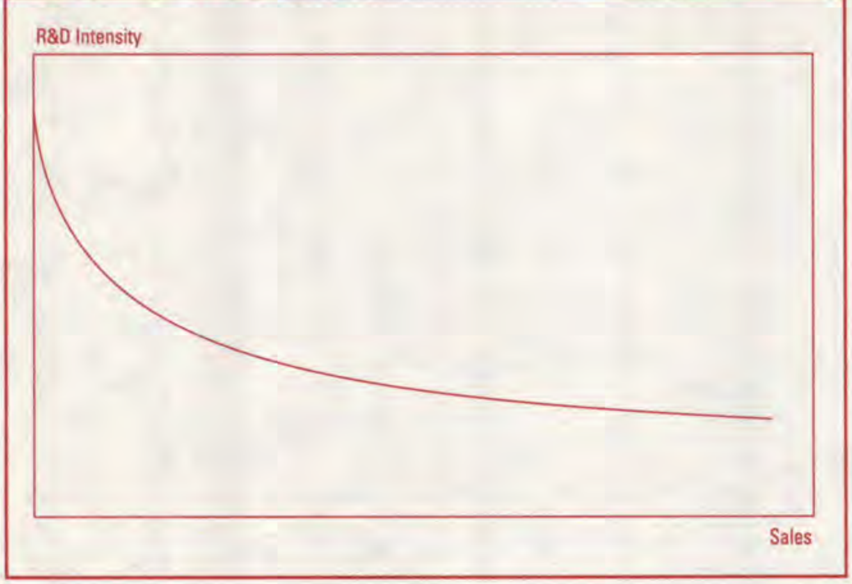
The role of research and development (R&D) in the generation of wealth and the maintenance or improvement of living standards in an industrialized economy has become more crucial with the rapid globalization of the world's economy and the resulting emphasis on the performance of strategic R&D. The reasons for the lower levels of R&D performed in Canada relative to most of its main competitors continue to command the attention of policy makers. In 1992, for example, industrial R&D in Canada stood at 0.81 percent of gross domestic product, compared with average levels of approximately 1.5 percent for the Group of Seven (G-7) most industrialized nations as a whole.[1]

Many reasons are given for the lower than average industrial R&D performance of Canadian industry relative to that of other industrialized countries. The large number of resource-based industries, the lack of a large defence sector and the large component of the economy owned by foreign interests have all been cited as factors limiting R&D investment by Canadian industry. Foreign ownership as a factor in restricting Canada's R&D performance is often supported by statistics indicating that the R&D expenditures of foreign-controlled firms are lower than those of their Canadian counterparts. Statistics Canada *(Science Statistics* 17(2), Catalogue No. 88-001), reports that the intramural expenditures of Canadian firms in 1990 represented 1.6 percent of sales, while the corresponding figure for foreign-controlled firms was 1.4 percent.

When data from all firms are aggregated, however, there is strong evidence that, as sales increase, the R&D intensity (R&D expenditures divided by sales) decreases (see Figure 1). The Conference Board of Canada has found in several annual surveys of industrial R&D performers in Canada that, of those firms that do perform R&D, the smaller firms usually report higher R&D expenditure growth rates, and are also more optimistic of continued growth in their R&D spending (see Figure 2).

The question arises: Given the fact that foreign-owned firms conducting business in Canada on average are larger than their Canadian-owned counterparts, is the relatively lower R&D intensity of foreign-controlled firms a result of their ownership or of their size? In the face of these competing statistics, would further analysis of the data support or refute the suggestion that foreign-owned firms are

**Figure 1 — Intensity versus Sales**

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[1] Statistics Canada, *Industrial Research and Development Statistics*, Catalogue No. 88-202, 1992, Table 1.1, p. 14.

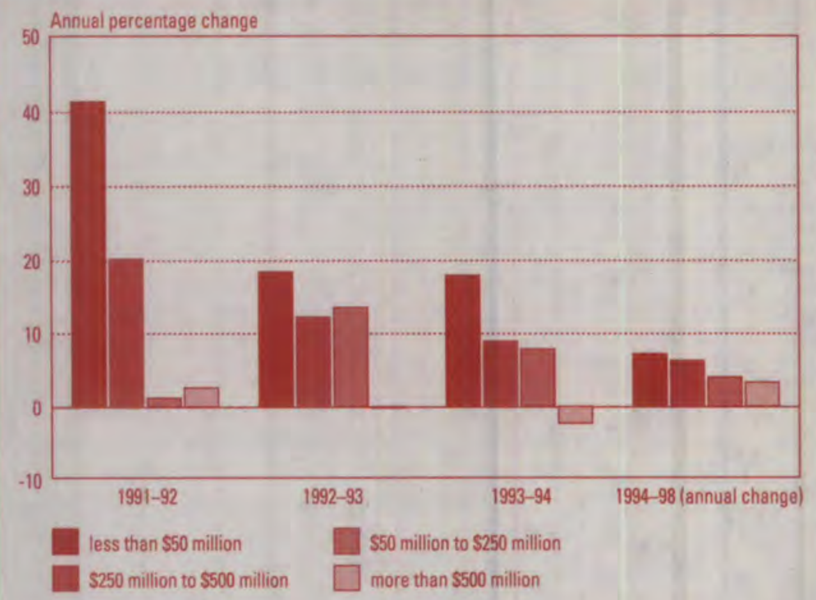
"bad corporate citizens"? Is it possible that industrial R&D policy to date has been influenced by the untested assumption that R&D intensity is negatively correlated with ownership, when the phenomenon under observation is dominated by the effect of size?

The determinants of R&D effort have been given considerable attention in the literature and are often examined using regression analysis. Studies employing regression analysis to explain the determinants of R&D activity have tested a wide variety of models containing many possible determinants such as market structure, government participation, appropriability and diversification.[2] The hypotheses that changes in R&D are associated with changes in the size of the performing firms and ownership highlights two additional determinants of R&D activity that have been tested often in the literature.

The importance of scale in the willingness of firms to perform R&D has been popularized by Schumpeter.[3] He argues that the "lumpiness" of R&D activity restricts the ability of smaller firms to cross the inventive activity threshold and to enjoy the benefits arising from innovation. Larger firms, in contrast, have a larger pool of resources to draw upon and are in a better position to allocate the larger sums of capital required for innovative activity.

Studies using Canadian data such as those by Globerman, Howe and McFetridge, and Frankl[4] have tested the importance of scale. They have also given considerable attention to the importance of ownership as a determinant in the willingness of firms to perform R&D in Canada. Frankl hypothesizes that ownership may be important because of what she calls "truncated" R&D functions, where attempts by U.S.-based subsidiaries to take advantage of economies of scale translate into the performance of additional R&D projects at existing facilities in the United States, rather than the creation of new ones in Canada.

Figure 2 — R&D Spending Intentions, by Sales




*Source:* Warda, *op. cit.*

[2] For a concise review of the literature on the determinants of R&D activity, refer to an article by M. I. Kamien and N. L. Schartz, "Market Structure and Innovation: A Survey," *Journal of Economic Literature* 13 (1975): 1–37.

[3] J. A. Schumpeter, *Capitalism, Socialism and Democracy* (New York: Harper, 1942).

[4] S. Globerman, "Market Structure and R&D in Canadian Manufacturing Industries," *Quarterly Review of Economics and Business* 13 (1973): 59–68; J. D. Howe and D. G. McFetridge, "The Determinants of R&D Expenditures," *Canadian Journal of Economics* 9 (1976): 57–71; R. Frankl, "A Cross Sectional Analysis of Research and Development Intensity in Canadian Industries with Particular Emphasis on Foreign Control" (Ottawa: Industry, Trade and Commerce, 1979) p. 16.

Starting with an exponential model:

(1) $Y = AX^b$

where $Y$ = R&D Exp
$X$ = Sales

A logarithmic formulation compresses the data and reduces heterosceditity:

(2) $\ln Y = A_0 + b_0 \ln X$

The model equation takes the form:

$$\ln(\text{R\&D Expenditures}) = A_0 + A_1(\text{Dummy}) + B_0\ln(\text{Sales}) + B_1(\text{Dummy})(\text{Sales})$$

where Dummy = 0 for Canadian-controlled firms, and 1 for foreign firms.

The analysis pivots on the sales elasticity of R&D; that is, the ratio of the rate of change in R&D performance to the rate of change in sales.

The elasticity of Y with respect to X can be derived by first differentiating Equation 1:

(1a) $dy/dx = AbX^{b-1}$

Then dividing Equation 1 by X gives:

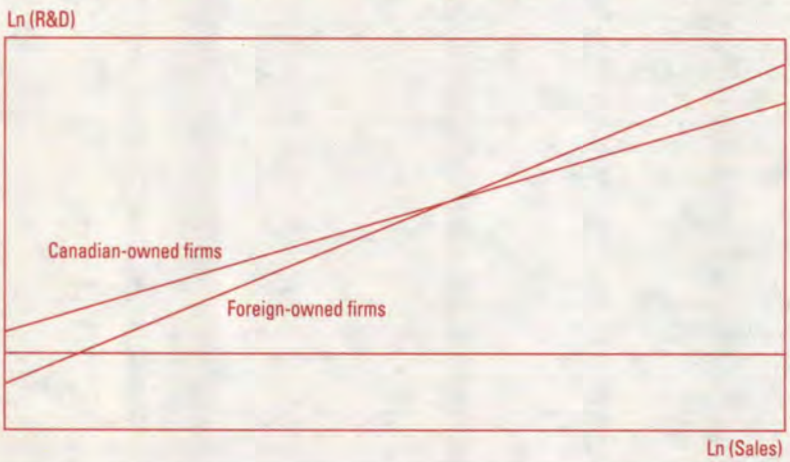
(1b) $Y/X = AX^{b-1}$

Finally, multiplying both sides of Equation 1a by X/Y gives:

(1c) $dy/dx * X/Y = AbX^{b-1} * X/Y$
$= bAX^{b-1} / AX^{b-1}$
$= b$

Thus b is the sales elasticity of R&D.

Typical Regression Lines for Canadian-owned and Foreign-owned R&D Peformers




## The Model

Link et al[5] examine various models of industrial R&D performance and conclude that an exponential model is the most appropriate. This model has several advantages. The model allows for the possibility that R&D intensity varies with size. If R&D intensity is constant with size, the relationship is linear and the exponent equals unity. But if, as suggested by the aggregate statistics, R&D intensity decreases with size, the exponent is less than unity.

The importance of ownership as a determinant of R&D effort can be tested by including dummy variables (see box). The dummy variables represent the estimated differential value of each parameter and its level of significance for foreign-owned performers, compared with Canadian-owned performers.

Most of the analyses focus on the estimated elasticity of Canadian-owned performers and on the estimated differential elasticity of foreign-owned performers. Schumpeter's scale hypothesis suggests that the elasticities have a value greater than unity. In other words, a percentage increase in sales is accompanied by a larger percentage increase in R&D effort. The widely held belief that foreign-owned firms are "bad corporate citizens" suggests that the foreign elasticities ought to be significantly less than Canadian elasticities for a given industrial sector.

[5] A. N. Link, T. G. Seaks, S. R. Woodbery, "Firm Size and R&D Spending: Testing for Functional Form," *Southern Economic Journal* 54 (4) [1988].

## The Data

The model is tested using pooled cross-sectional time series data on R&D in Canadian industry collected by Statistics Canada, from which 14 934 observations of R&D-performing firms for 1981–89 are drawn.[6] This gives a sufficient number of observations to allow estimation on a sector basis by Standard Industrial Codes. The measures of scale used are sales and total employment, and the measures of R&D activity are R&D expenditures and R&D employees.

The conclusions reached can then be tested using a different set of data collected from the Conference Board of Canada's 1994 Survey of Research and Development Intentions in the Canadian Corporate Sector.[7] The sample includes 1992 data for 114 R&D performers. The sample size does not permit model estimation on an industry level. The model is first estimated for the entire data set and then estimated for performers of low, medium and high R&D intensity.[8] R&D effort and scale are measured using R&D expenditure and sales, respectively. Approximately half the firms have sales less than $250 billion, and 66 of the firms are Canadian-owned.

The summary statistics contained in Table 1 highlight important differences and similarities between the two samples. The average size of performers in the Conference Board of Canada sample is considerably larger than that in the Statistics Canada sample. This may explain in part why the average R&D effort of Canadian-owned performers is lower than their foreign-owned counterparts in the Statistics Canada sample but higher in the Conference Board sample. The Conference Board of Canada sample also has proportionately more foreign-owned performers than the Statistics Canada sample. Despite the above difference, R&D intensities in the Conference Board of Canada and Statistics Canada samples are the same, 1.5 percent.

Table 1 — Summary Statistics of the Two Samples

| | Statistics Canada data set 1981–89 | Conference Board of Canada data set 1993 |
|---|---|---|
| Number of observations: | | |
| Canadian-owned | 12 531 | 66 |
| Foreign-owned | 2 403 | 48 |
| Total | 14 934 | 114 |
| Average sales ($000): | | |
| Canadian-owned | 35 036 | 963 310 |
| Foreign-owned | 276 754 | 1 251 800 |
| Average R&D expenditures ($000): | | |
| Canadian-owned | 765 | 17 395 |
| Foreign-owned | 2 892 | 15 062 |
| Average intensity (%): | | |
| Canadian-owned | 2.2 | 1.8 |
| Foreign-owned | 1.0 | 1.2 |
| All performers | 1.5 | 1.5 |

*Source:* See text.

## The Results

The analysis focuses on the results of the R&D expenditure/sales models. The results based on the employee data model are used as a check on the R&D expenditures/sales results. The results of both tests indicate that while scale is a significant determinant in explaining a firm's willingness to perform R&D, Schumpeter's scale hypothesis is rejected. The model estimates using the Statistics Canada data set find only one industry (foreign aircraft and parts) where the estimated elasticity is greater than unity (see Table 2).[9] The estimated elasticities of the remaining 22 industries are all found to be significantly less than unity.

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[6] Twenty of the 46 sectors were dropped from the analysis when the sales and R&D expenditure measures were used. The sectors dropped from the analysis included those with fewer than 27 data points or those that may be characterized as catch-all sectors such as other transportation, not elsewhere classified. The mining, primary metals and wholesale services industries were also dropped from the analysis of the R&D expenditure and sales model because of evidence of autocorrelation, leaving the 23 sectors shown in Table 2. Twenty-two sectors were dropped from the analysis using employment measures when the same criteria were used.

[7] This work was carried out under contract to Industry Canada by J. Warda and R. J. Squires

[8] Low intensity refers to firms with an R&D/sales ratio less than 1 percent; medium intensity refers to firms with an R&D/sales ratio between 1 and 3 percent; and high intensity refers to firms with an R&D/sales ratio greater than 3 percent.

[9] The results of the model $\mathrm{Ln(R\&D)} = A_0 + B_1 \ln(\mathrm{Sales}) + e$, where the ownership dummy variable is omitted, although not reported, also lend no support for Schumpeter's scale hypothesis.

Table 2 — Coefficient Estimates of Canadian and Foreign Firms, (R&D Expenditures versus Sales)[a]

| | Canadian | Foreign |
|---|---|---|
| Agriculture | 0.239 | 0.642 |
| Crude petroleum and natural gas | 0.318 | 0.508[b] |
| Food | 0.326 | 0.653[b] |
| Beverages and tobacco | 0.411 | 0.659[b] |
| Rubber products | 0.271 | 0.708[b] |
| Plastic products | 0.383 | 0.757[b] |
| Textiles | 0.450 | 0.793[b] |
| Paper and allied products | 0.655 | 0.240[b] |
| Fabricated metal products | 0.284 | 0.661[b] |
| Machinery | 0.439 | 0.655[b] |
| Aircraft and parts | 0.660 | 1.142[b] |
| Motor vehicle parts and accessories | 0.485 | 0.512 |
| Telecommunication equipment | 0.854 | 0.828 |
| Electronic parts and components | 0.535 | 0.736 |
| Business machines | 0.631 | 0.850[b] |
| Non-metallic mineral products | 0.219 | 0.642[b] |
| Refined petroleum and coal products | 0.354 | 0.710[b] |
| Pharmaceutical and medicine | 0.527 | 0.814[b] |
| Scientific and professional equipment | 0.472 | 0.418 |
| Construction | 0.213 | 0.426[b] |
| Finance and insurance | 0.334 | 0.482 |
| Computer and related services | 0.551 | 0.428 |
| Engineering and scientific services | 0.418 | 0.649[b] |

[a] $R^2$ varies from 0.26 to 0.76. While these values may seem low compared with some of the results obtained by Link et al, their sample comprises only the large R&D performers included in *Business Week*'s annual "R&D Scoreboard," while the Statistics Canada data set embraces all R&D performers, including some for whom R&D is only a marginal function.

[b] Denotes those intercepts and elasticities significantly different across ownership.

The same result is found when the Conference Board of Canada data are used. Model estimates for the entire data set find the elasticities for both Canadian and foreign-controlled firms to be significantly less than unity. Schumpeter's scale hypothesis is again refuted when the Conference Board data are organized by low, medium and high-intensity firms. These estimates are higher than those found for the entire Conference Board data set; however, the elasticities are not found to be significantly greater than unity.

## Analysis

The study offers little support for the hypothesis that foreign-owned performers are less willing to perform R&D in Canada than their Canadian-owned counterparts. Based on the Statistics Canada data, foreign-owned performers are found to increase R&D expenditures by a greater percentage, given some percentage increase in sales, than their Canadian-owned counterparts in 21 of the 23 industries considered. The estimated differential elasticities are significantly greater in 15 of those 21 industries. The model estimates for the entire Conference Board data set also show foreign-owned firms to have a greater, although not significantly greater, willingness to increase R&D effort as scale increases. This finding is supported further when the model is estimated separately according to R&D intensity. The sales elasticity of R&D for high-intensity, foreign-owned firms is found to be significantly greater than their Canadian-owned counterparts. No significant difference in the sales elasticities of R&D of Canadian- and foreign-owned performers is found for low- and medium-technology firms.

Coupled with the observation that in virtually every sector Canadian firms have a lower average size than the foreign-controlled firms, these results suggest it is the generally smaller size of Canadian firms that accounts for their observed higher R&D intensities. If Canadian firms were to maintain their R&D performance characteristics as their mean sizes were adjusted to correspond with those of their foreign counterparts, their R&D intensities would be lower.

## Discussion and Conclusion

The policy issue, as originally set out, is whether the observed lower aggregate foreign R&D intensity is the result of size or ownership. In policy terms, the evidence suggests that size and not ownership is the major determinant of R&D intensity and that, except for small and medium-sized enterprises, foreign-controlled firms generally have higher R&D intensities than Canadian ones. The observed differences in aggregate intensities are probably related to the difference between the average size of Canadian R&D performers and foreign-controlled R&D performers. This result is confirmed on a highly aggregated basis by the Conference Board data.

The data suggest the following conclusions:

- There are sectoral differences in elasticity of R&D expenditures, which are not easily explained on the basis of technological sophistication.
- In general, foreign-controlled firms' R&D expenditures are less inelastic than those of Canadian-controlled firms.

At the sectoral level, structural differences between foreign and Canadian R&D performers are found to be widespread, as measured by the significantly higher elasticities for foreign-controlled performers. Emphasis is placed on elasticity because of the interpretation of elasticity as a measure of the willingness of firms to invest additional resources in R&D as the size of the firm increases, a finding of considerable importance in terms of estimating the contribution foreign firms can make to the economy. The models suggest that Canadian firms of the same size as their foreign-controlled counterparts will continue to be outperformed by their foreign counterparts.

Analysis of the Conference Board data also reveals marked differences in the attitudes of R&D-performing firms in Canada, determined by size and ownership, toward various policies and programs put in place by governments. In general, large foreign-controlled firms believe that Canada is a good place to do R&D, while small Canadian-controlled firms are pessimistic about R&D in Canada and about government programs that encourage R&D, in particular.

These outcomes suggest that there may have to be a set of government policies and programs for the support and encouragement of industrial R&D. At the minimum, there are four distinct categories of firms doing R&D in Canada:

- small Canadian-controlled
- small foreign-controlled
- large Canadian-controlled
- large foreign-controlled.

What policies might be required to get large Canadian-controlled firms to act more like large foreign-controlled firms, at least when it comes to investment in R&D? The Conference Board data set suggests that the foreign-controlled equivalents are very happy with the R&D tax credit program. Foreign enterprises may have some factors that confer on them advantages not available to the average Canadian firm of the same size. These factors probably include access to financing, access to management skills and a greater ability to capture rents on technology developed in Canada.

Small Canadian-controlled firms do more R&D than small foreign-controlled firms but, as suggested by the Conference Board data, are not happy with the current arrangements. Possible policy initiatives to improve the performance of Canadian firms include ones common to all enterprises (access to financing, better management, etc.). Policies specific to technology-based firms would help to realize the value of technologies developed by Canadian firms in overseas markets through programs providing assistance to market them or otherwise maintain their competitive advantages.

Recent analyses suggest that the R&D tax credit system in Canada does not confer any special incentive to small companies and that all tax measures taken together confer more favourable treatment to larger companies. This may be a factor in their general disenchantment with the system, as revealed in the Conference Board data. Incremental R&D expenditures occurring as a result of tax incentives show no significant differences between large and small companies. This may imply that non-tax measures may be required to stimulate preferentially small and medium-sized R&D performers.

The lower R&D intensities of foreign-controlled small and medium-sized enterprises also call into question what steps are needed to improve the R&D efforts of this group. Their performance may be low simply because they can get technology at less than market cost from their foreign parents. Perhaps in an overall sense, this is good for Canada, in that the economy is thus acquiring technology at a lower cost.

# Canada's Comparative Cost Advantage in Performing R&D

*by Robert Squires**

The emerging global economy poses few barriers to the movement of goods, services, and physical and human capital. This is placing considerable pressure on national and local governments to provide economic environments that will help existing and new business interests to succeed. Globalization also results in a knowledge-driven, wealth-creating economy. These developments represent a challenge for most, if not all nations, including Canada. However, Canada has an important advantage over its competitors in industrial research and development (R&D) services, an area that is widely considered essential for success in this global, knowledge-based economy.

The importance of R&D for both firms and nations is well documented and understood. One of the challenges facing nations is to encourage and attract R&D-performing firms. A firm's decision on where to perform its R&D will depend among other considerations on the relative cost associated with a given location. Recent evidence from the Conference Board of Canada[1] suggests that Canada's tax system,[2] the quality of direct government support for R&D and the availability of qualified research professionals all lead to a relatively low national cost for performing R&D. This favourable cost position represents a considerable advantage for Canada in terms of encouraging firms to increase their levels of an activity, viewed as crucial for survival in the new economy. There is evidence, however, that the cost advantages of performing R&D in Canada are not fully used or recognized by many of the Canadian-owned firms currently carrying out R&D in the country.

## Cost per Researcher

Using data from the Organisation for Economic Co-operation and Development (OECD) as contained in *Basic Science and Technology Statistics 1993*, the industry-level average cost of business enterprise expenditures on R&D (BERD) per research scientist and engineer (RSE), for each of the Group of Seven (G-7) most industrialized nations can be calculated. The results indicate that Canada's average cost per researcher (salaries, operating costs and capital) is the lowest of all G-7 nations (see Table 1, column 1). Removal of the industrial sectors for which data for all G-7 nations are unavailable leaves Canada's overall ranking unchanged (see Table 1, column 2).

As shown in Table 2, the results of the electrical equipment, chemicals and drugs industries underscore the variation in average BERD per research scientist and engineer across industries.

* This analysis was prepared for the Secretariat for Science and Technology Review by Robert Squires, an economics research consultant working in Ottawa.

[1] Conference Board of Canada, *Canadian R&D Tax Treatment*, Report 125-94 (Ottawa: Conference Board of Canada, 1994); and Conference Board of Canada, *R&D Outlook, 1994* (Ottawa: Conference Board of Canada, 1993).

[2] For more information on the tax system with regard to R&D, see Volume I of the *Resource Book*, pp. 11 and 29.

In addition to meeting medium- and long-term goals of improved competitiveness, R&D activity has an immediate positive effect on national employment levels. Industrial R&D professional employment totalled 29 330 in 1990. The industries with the greatest number of RSE positions included computers (2 270), aerospace (2 120), electronics (7 300), computer services (4 470) and engineering services (2 450).

Funding for industrial R&D from abroad accounts for a sizable proportion of both total BERD performed in Canada (18 percent) and total foreign direct investment (6 percent). Given the average cost per researcher, it is estimated that BERD from abroad produced the equivalent of approximately 5 100 jobs for RSEs in 1988. Since there is approximately one support staff position for each researcher, about 10 000 jobs have been created by foreign investment in R&D activities in Canada.

Table 1 — BERD/RSE for G-7 Nations (1989 constant Canadian dollars)[a]

| | BERD/RSE (1) | BERD/RSE (2) |
|---|---|---|
| Canada | $171 078 | $207 294 |
| U.S. | $185 031 | $215 698 |
| U.K. | $198 298 | $224 662 |
| Germany | $252 037 | $337 305 |
| Italy | $269 314 | $307 178 |
| France | $302 426 | $369 904 |
| Japan[b] | $244 941 | $257 878 |

[a] The data used for Canada and France are for 1988 and have been adjusted by each nation's implicit gross domestic product deflator. Data for the remaining countries are for 1989. Statistics Canada has found that, in general, the implicit gross domestic product deflator is a good approximation for an R&D price index; see J. I. Bernstein, *Price Indexes for Canadian Industrial Research and Development Expenditures* (Ottawa: Statistics Canada, 1992).

[b] Based on the data supplied from Japan, the 1989 BERD/RSE for columns 1 and 2 of Table 1 for Japan are $171 459 and $173 896, respectively. The OECD Secretariat notes that Japan's R&D personnel data are expressed as the number of physical persons, rather than in terms of full-time equivalents. Japanese authorities estimate that Japan's R&D personnel in the business sector may be cut by as much as 30 percent. According to these estimates, the BERD/RSE ratios of columns 1 and 2 would be as shown.

*Source:* Industry Canada estimates based on data from Organisation for Economic Co-operation and Development, *Basic Science and Technology Statistics* (Paris: OECD, 1993).

Table 2 — BERD/RSE in Selected Industries (1989 constant Canadian dollars)[a]

| | Electrical equipment | Chemicals | Drugs |
|---|---|---|---|
| Canada | 152 866 | 141 370 | 211 151 |
| U.S. | 171 295 | 185 243 | 209 859 |
| U.K. | 154 000 | 222 592 | 283 250 |
| Germany | 172 136 | 498 940 | 347 330 |
| Italy | 183 734 | 169 793 | 343 928 |
| France | 274 817 | 375 967 | 322 321 |

[a] The data used for Canada and France are for 1988 and have been adjusted by each nation's implicit gross domestic product deflator. Data for the remaining countries are for 1989. Statistics Canada has found that, in general, the implicit gross domestic product deflator is a good approximation for an R&D price index; see J. I. Bernstein, *Price Indexes for Canadian Industrial Research and Development Expenditures* (Ottawa: Statistics Canada, 1992).

*Source:* Industry Canada estimates based on data from Organisation for Economic Co-operation and Development, *Basic Science and Technology Statistics* (Paris: OECD, 1993).

## Additional Evidence

Canada's direct R&D costs do not include other cost advantages. For example, Canada's R&D tax credit system is the most generous among industrialized nations. While this does not affect the R&D expenditure and RSE statistics above (since the tax credits are based on actual R&D expenditures), the tax credits reduce the companies' tax exposure and hence increase their overall profitability.

The Conference Board of Canada has found that foreign firms are fully aware of these advantages. Its 1994 R&D Intentions Survey found that foreign-owned performers were far more positive about the Canadian tax system than were Canadian-owned firms. Nearly 43 percent of foreign-owned firms responded that Canada has a better tax system than the U.S., compared with approximately 24 percent of Canadian-owned performers who held the same view. The foreign-owned firms having a favourable view of Canada's tax system tended to be larger and highly R&D intensive. The authors of the survey suggest that the difference in attitudes across firms of various ownership, size and R&D intensity may be due to greater awareness and knowledge of the tax system. Larger firms, especially large multinational firms, have greater resources to collect comparative information on tax laws when deciding on where to perform R&D. On the other hand, the attitudes of smaller companies (which are more likely to be Canadian-owned) may also be affected by their lack of sufficient income to realize the full benefits of the tax system.

The survey also found that large, R&D-intensive, Canadian-owned firms tended to prefer direct government support programs in Canada over government support programs in the U.S. There was no clear preference among foreign-owned firms. As with their views on the tax system, the firms with more intensive R&D also tended to be more supportive of direct government R&D programs in Canada. Firms characterized as having low R&D intensity showed a clear preference for direct government support in the U.S. The Conference Board of Canada speculates that fewer opportunities to take advantage of government support may arise, because of the lack of a benchmark against which to compare each nation's respective programs.

Attitudes and perceptions regarding Canada's overall cost per researcher (OCR) were also found to differ among foreign- and Canadian-owned performers. Forty-four percent of the foreign-owned firms surveyed indicated that they perceived Canada to have a lower OCR relative to the U.S. Of the Canadian-owned firms surveyed, 31.5 percent held the same view. Canadian-owned small to medium-sized enterprises viewed the U.S. OCR as being more favourable.

These perceptions support earlier survey findings that larger firms, both Canadian- and foreign-owned, are more knowledgeable about the costs involved in performing R&D and more rational in their decision making. Foreign-owned firms were found to regard the supply of highly qualified personnel in Canada. as having favourable attributes. The perception among Canadian-controlled small and medium-sized businesses that OCR is lower in the United States may be explained in part by their lesser ability to attract and hire research professionals.

## Conclusion

The evidence suggests that many firms recognize and are taking advantage of Canada's cost attractiveness as a place to perform R&D. In addition to generating knowledge needed to improve Canadian competitiveness, expenditures on R&D result in many highly skilled, high-paying jobs. The attractiveness of Canada's overall cost per researcher, tax system and direct government support of R&D appear to be recognized by those firms that have the resources required to make such an assessment. Canada's advantages as a place to conduct R&D, however, are not fully recognized or used by many firms currently performing R&D in the country. The challenge to governments at all levels is to promote accessibility and information so that the cost benefits of performing R&D in Canada are more widely available.

# Trade in Advanced Technology Products

*by Robert Squires**

The rapid development of technology is affecting virtually every aspect of Canadian business from production to marketing. The ability of firms to employ sophisticated production equipment and to create products containing advanced technologies is viewed as crucial for their innovation and competitiveness. So too the wealth and competitiveness of national economies are closely linked to their ability to employ and generate such products.

Exports of advanced technology products (ATPs) are generally perceived as a positive indicator of a nation's competitiveness and technological development. Conversely, imports of ATPs are often viewed as symptomatic of technological weakness. Now more than ever before, it is important that firms acquire the most advanced technology available throughout the world in order to compete in the highly competitive global economy. Investment in ATPs from abroad may be a logical business decision that has a positive return on Canada's investment, competitiveness and future export performance.

## U.S. High-tech Trade Statistics

Soon after the United States changed to the Harmonized Commodity Description and Coding System (HS), it began to include ATP trade among the Census Bureau's regular monthly trade statistics. About 500 of some 22 000 commodity classification codes used in reporting U.S. merchandise trade were identified as "advanced technology."

To be included in this category, a product must contain leading-edge technology from a recognized advanced technology field such as biotechnology. The value of the high-tech element must constitute a significant proportion of the total value of the selected classification code.

The Census Bureau states that this product- and commodity-based measure of advanced technology differs from the broader high-tech trade measures based on the Standard Industrial Code as employed by the Organisation for Economic Co-operation and Development (OECD), because the U.S. classification alleviates aggregation biases present in traditional high-tech trade measures. The broader OECD measures are biased by the inclusion of all products and commodities produced by a particular industry group, regardless of the level of technology embodied in the commodities. Moreover, the U.S. list of advanced technologies is open for periodic revision, with new technologies added and old ones dropped as technologies change.

Ten fields are used in classifying advanced technology products:

- biotechnology
- life sciences
- opto-electronics
- computer and telecommunications
- electronics
- computer integrated manufacturing
- materials design
- aerospace
- weapons
- nuclear technology.

There can be overlap among the selected fields (for example, biotechnology and life sciences), and specific products and classifications may contain technologies from more than one field.

* This analysis was prepared for the Secretariat for Science and Technology Review by Robert Squires, an economics research consultant working in Ottawa.

## Industry Canada Application of the U.S. Model

This article updates an earlier Industry Canada estimate[1] of Canada's trade in ATPs, based on the list of ATPs developed by the U.S. Bureau of the Census. The U.S. Department of Commerce list was used simply because there is no international consensus on what is and what is not an ATP. ATPs by definition are products, and therefore do not necessarily reflect advances in processing technologies, unless the processing machinery itself is an ATP. Thus trade in ATPs may not reflect innovation in the resource sectors.

To ensure equitable comparisons, all Canadian import data were converted to 1986 constant dollars using the Bank of Canada import implicit price index. Exports were similarly indexed by the export implicit price index.

## Results

As shown in Table 1, Canada's trade in ATPs for 1990–93 constituted approximately 12 percent of the total national merchandise trade. The rapid expansion of Canada's merchandise trade was reflected in growth in ATP trade. Trade in ATPs grew by 19 percent, compared with a 21-percent increase in merchandise trade for 1990–93. Imports and exports of ATPs grew by 21 percent and 15 percent, respectively, contributing to a 29-percent increase in the ATP trade deficit.

The United States is our overall largest trading partner. Trade in ATPs is no exception (Table 2). The relative importance of the U.S. is, however, slowly declining. The percentage of Canada's total trade in ATPs with the U.S. declined in 1993 to 65 percent of total ATP volume, compared with 69 percent in 1990. The percentage of Canada's total ATP volume with the European Community and Japan were constant at 11 percent and 7 percent, respectively.

Table 1 — Canada's Imports and Exports of High-tech Products, 1990–93

| | Imports | Exports | Balance | Total | Total as share of merchandise trade |
|---|---|---|---|---|---|
| | (millions of 1986 constant dollars) | | | | (%) |
| 1990 | 21 480 | 12 697 | -8 783 | 34 177 | 12 |
| 1991 | 23 535 | 14 263 | -9 271 | 37 798 | 13 |
| 1992 | 25 566 | 14 298 | -11 268 | 39 865 | 13 |
| 1993 | 26 001 | 14 660 | -11 341 | 40 661 | 12 |
| Change from 1990 to 1993 (%) | 21 | 15 | 19 | 19 | |

*Source:* Industry Canada estimates.

Table 2 — High-tech Trade, by Region, 1993

| | Total volume | (%) | Exports | (%) | Imports | (%) | Balance | (%) |
|---|---|---|---|---|---|---|---|---|
| | (millions of 1986 constant dollars) | | | | | | | |
| United States | 26 414 | 65 | 10 716 | 73 | 15 699 | 60 | -4 983 | 43 |
| Japan | 2 671 | 7 | 195 | 1 | 2 475 | 10 | -2 280 | 20 |
| European Community | 4 402 | 11 | 1 731 | 12 | 2 671 | 10 | -940 | 8 |
| Other | 7 173 | 18 | 2 018 | 14 | 5 156 | 20 | -3 138 | 28 |

*Source:* Industry Canada estimates.

Table 3 — High-tech Trade Balances, by Region, 1990–93

| | World | U.S. | Japan | European Community | Other |
|---|---|---|---|---|---|
| | (millions of 1986 constant dollars) | | | | |
| 1990 | -8 783 | -4 771 | -1 812 | -748 | -1 452 |
| 1991 | -9 271 | -3 594 | -2 218 | -1 402 | -2 058 |
| 1992 | -11 267 | -4 709 | -2 265 | -1 523 | -2 770 |
| 1993 | -11 341 | -4 983 | -2 280 | -940 | -3 139 |

*Source:* Industry Canada estimates.

The rapid growth and brisk competition from many Pacific Rim nations, such as Singapore, Republic of Korea and Thailand, are reflected in Canada's ATP trade statistics. It is with this region, classified in this paper among "Other" nations, that Canada has experienced the largest percentage increase in trade volume in ATPs. Total trade in ATPs

[1] Industry, Science and Technology Canada, "Trade in Advanced Technology Products," S&T Economic Analysis Division, ISTC, Ottawa, 1992. The 500 ATPs in the U.S. list were aggregated to the six-digit level in order to make a successful crossover to the Canadian HS commodity system, which reduced the number of commodities to 222.

Table 4 — High-tech Trade Balance, by Technology, 1990–93

| | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|
| | (millions of 1986 constant dollars) | | | |
| Biotechnology | -54 | -65 | -79 | -120 |
| Life sciences | -1 948 | -2 016 | -2 169 | -2 431 |
| Opto-electronics | -210 | -203 | -283 | -150 |
| Computers and telecommunications | -3 754 | -4 215 | -4 761 | -5 121 |
| Electronics | -1 790 | -1 661 | -2 129 | -2 823 |
| Computer integrated manufacturing | -1 191 | -1 360 | -1 088 | -1 479 |
| Material design | -470 | -520 | -530 | -200 |
| Aerospace | 670 | 764 | -151 | 954 |
| Weapons | -243 | -247 | -278 | -273 |
| Nuclear technology | 208 | 251 | 200 | 302 |
| Total | -7 912 | -8 307 | -10 593 | -11 190 |

*Source:* Industry Canada estimates.

Table 5 — Canadian Import/Export Balance, by Technology, Selected Regions, 1993

| | U.S. | Japan | European Community | Other |
|---|---|---|---|---|
| | (millions of 1986 constant dollars) | | | |
| Biotechnology | -124 | -4 | 6 | 3 |
| Life sciences | -1 484 | -64 | -677 | -204 |
| Opto-electronics | -77 | -53 | -8 | -12 |
| Computers and telecommunications | -2 153 | -1 469 | -58 | -1 442 |
| Electronics | -229 | -425 | -195 | -1 974 |
| Computer integrated manufacturing | -1 089 | -292 | -214 | 117 |
| Material design | -192 | -9 | -11 | 12 |
| Aerospace | 354 | 48 | 211 | 342 |
| Weapons | -270 | -10 | -10 | 17 |
| Nuclear technology | 281 | -0.4 | 17 | 4 |

*Source:* Industry Canada estimates.

Table 6 — Rates of Change of Imports, Exports and Balance, by Technology, 1990–93

| | Imports | Exports | Balance |
|---|---|---|---|
| | (percent) | | |
| Biotechnology | 74 | 32 | 119 |
| Life sciences | 31 | 63 | 25 |
| Opto-electronics | -10 | 56 | -28 |
| Computers and telecommunications | 38 | 40 | 36 |
| Electronics | 19 | -8 | 58 |
| Computer integrated manufacturing | 36 | 54 | 24 |
| Material design | -11 | 158 | -57 |
| Aerospace | -18 | -9 | 42 |
| Weapons | 6 | -7 | 12 |
| Nuclear technology | -17 | 24 | 45 |
| Total | 21 | 15 | 29 |

*Source:* Industry Canada estimates.

with these nations increased by 51 percent for 1990–93 to reach $7.2 billion or 18 percent of Canada's total trade in ATPs. By comparison, ATP trade with Japan increased by 28 percent over the same period, and ATP trade with the U.S. and the European Community both increased by 13 percent.

Approximately $5 billion or 43 percent of Canada's 1993 total ATP trade deficit of $11.3 billion was with the U.S. (Table 3). Along with the rapid growth in volume, Canada's trade deficit in ATPs with "Other" nations increased by 116 percent during the four years considered, to reach $3.1 billion or 28 percent of Canada's 1993 ATP trade deficit. The 1993 trade deficits with Japan and the European Community were $2.3 billion and $0.9 billion, respectively, representing 20 percent and 8 percent of Canada's total ATP trade deficit.

## Sectoral Results

Canada has consistently been in a trade deficit position for each of the past four years in eight of the ten technologies (Table 4). The largest deficits occurred in the computers and telecommunications industry and in the electronics industry. The two industries with a surplus were the aerospace and nuclear technology industries. The deficit position for most technologies occurred across most regions (Table 5). The only notable exception is trade with nations included in the "Other" classification, where Canada had a surplus in six industries in 1993.

ATP trade is not entirely one way, however. Table 6 indicates that, despite an increase of 29 percent in Canada's overall trading deficit of ATPs for the years 1990–93, Canada's exports of ATPs, on a technology basis, have increased at a faster rate than imports in six of the ten technologies. The trends in growth rates of imports versus exports for 1990–93 translated into a decrease in Canada's trading deficit in the opto-electronics and the material design technologies.

## Conclusion

The list of ATP commodities, while not arbitrary, is certainly open for discussion. What is high-tech to one user may be low-tech in another application. Sophisticated voice synthesis chips are part of children's toys, yet talking dolls are not considered to be high-tech products.

Trade in ATPs is an indicator primarily of flows of capital goods. Very few of the commodities listed as ATP commodities are consumables; most are intermediate inputs or final products. With the exception of consumer electronics and some biological products, most ATP commodities represent investments in components of production facilities, which presumably will show a positive return on that investment. A resource-based economy such as Canada's may therefore show a deficit in computer equipment, since it imports process control equipment for resource-based industries. But this same investment in equipment allows these industries to compete more effectively in world markets.

The important conclusions relate to the flow and volume of trade, whether ATPs or total. The ATP trade statistics demonstrate that while the United States continues to be our largest technology partner, trade with the Pacific Rim countries is quickly growing in importance.

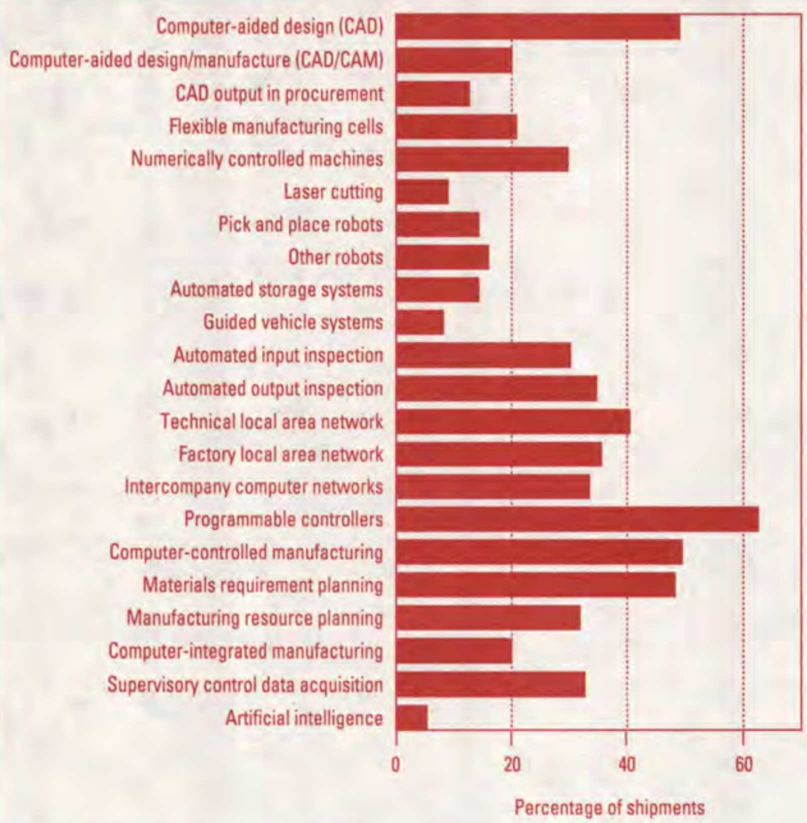
Many Canadian industries go through a make-or-buy decision when they decide to import some ATPs. Canadian industries are thus able to acquire technologies at market prices that they might not be able to develop themselves directly at any price. Trade in ATPs is a form of technology acquisition and diffusion. This exchange of technology is, of course, part of the globalization phenomenon.

# The Use of Advanced Manufacturing Technology in Canada

*by Robert Squires**

Advanced manufacturing technologies (AMTs) can be described as equipment or processes that improve the efficiency and quality of production using knowledge-based techniques. At the microeconomic level, the use of AMTs is viewed as vital for the survival of firms in the competitive global economy. At the macroeconomic level, employment of AMTs by firms is considered to be an indicator of national ability to compete successfully in the expanding global economic environment.

**Figure 1 — Use of Advanced Manufacturing Technologies in Manufacturing Establishments, by Technology, 1989**




*Source:* Statistics Canada uncatalogued working paper.

In light of the importance and pervasiveness of the use of advanced technologies, survey techniques have been developed to determine national usage and means of improving it. Statistics Canada collects information on the use of advanced technologies in Canadian manufacturing industries. Figure 1 shows the use of these technologies in terms of the percentage of total manufacturing shipments in Canada with which they are associated.[1] Figure 2 shows the use of AMTs for selected industrial sectors.

The use of AMTs is not restricted to industrial sectors that produce manufactured goods. The extraction and processing of raw materials can be just as AMT-intensive as the production of consumer goods. As Michael Porter[2] has shown, most of the major competitive industrial clusters in Canada are based on the extraction and processing of raw materials.

Figure 3 shows the results of an AMT survey in the mining industry.[3] Ninety-six percent of mines in Canada employ one or more advanced technologies, 49 percent employ 15 or more and 14 percent employ 20 or more. In general, the more internationally competitive sectors are more likely to use AMTs.

* This analysis was prepared for the Secretariat for Science and Technology Review by Robert Squires, an economics research consultant working in Ottawa.

[1] For a brief description of this work and the distribution of the use of AMTs by province, please see Vol. I in this series, p. 8.

[2] Michael Porter, *Canada at the Crossroads: The Reality of the New Competitive Environment* (Ottawa: Monitor, 1991).

[3] Industry, Science and Technology Canada, CANMET, Communications Canada and Statistics Canada, *Survey of Diffusion of Technology in the Mining Industry,* (Ottawa: Supply and Services Canada, 1990).

## Comparisons of Canadian and U.S. Use of AMTs

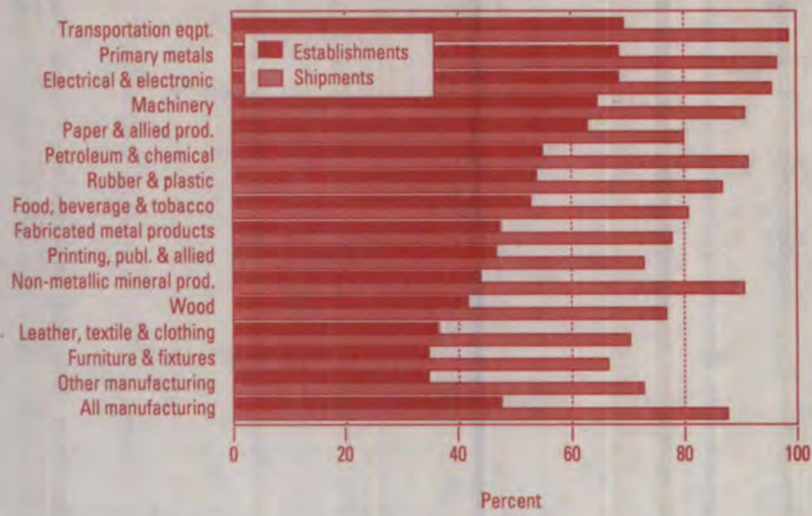
Comparable surveys have been carried out in Canada and the U.S.[4] These studies examined the use of 17 technologies in five technology classifications in Canada and the U.S. in five industries.[5]

The Statistics Canada[6] study indicates that a lower percentage of Canadian manufacturing firms, relative to their U.S. counterparts, use at least one AMT (58 percent compared with 74 percent). This trend is also found at the industry level. The industry level results are shown in Table 1.

The study also considers the intensity of use of AMTs in both countries according to the number of AMTs in use (see Figure 4).

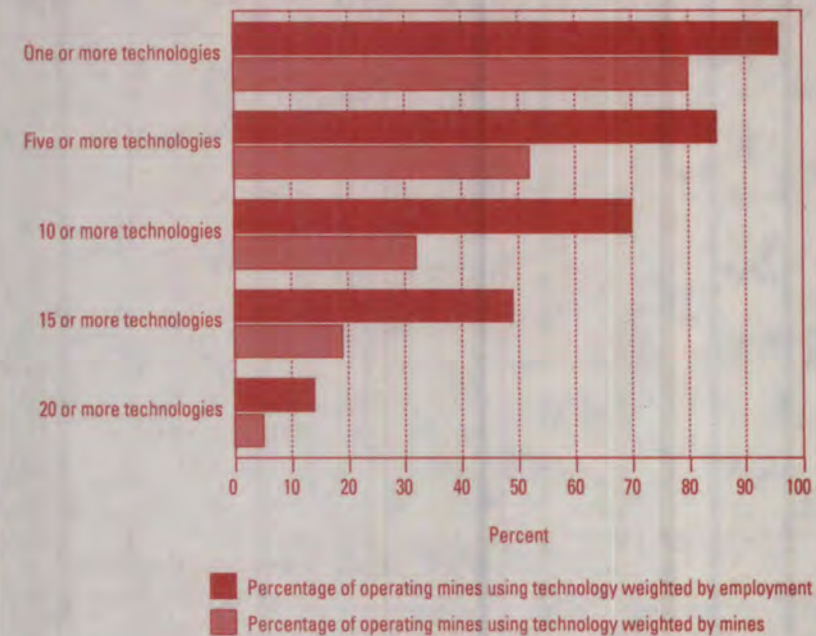
Similar results are obtained at the industry level. In three of the five sectors considered, a higher percentage of Canadian firms surveyed than U.S. firms employ only one AMT. The industry-level analysis finds a higher percentage of U.S. firms employing greater numbers of AMTs. The only exception to this finding is Canadian firms in the transport equipment industry, which on average employ between two and four AMTs.

Figure 2 — Use of at Least One Advanced Manufacturing Technology, March 1989




*Source:* Statistics Canada, *Indicators of Science and Technology 1989*, vol. 1, no. 4, Catalogue No. 88-002.

Figure 3 — Use of Advanced Mining Technology




*Source:* See footnote 3, p. 61.

[4] For Canadian data, see Statistics Canada, *Indicators of Science and Technology 1989, Surveys of Manufacturing Technology 1989*, vol. 1, no. 4, Catalogue No. 88-002. For U.S. data, see U.S. Department of Commerce, Manufacturing Technology 1988 (Washington, D.C.: Bureau of the Census, 1989).

[5] Statistics Canada removed from the Canadian sample firms with fewer than 20 employees and rearranged some of the industry groups as described in its *Standard Industrial Classification* (Ottawa: Supply and Services, 1980) at the three-digit level so that the results would be more comparable with those of the U.S. The treatment of non-respondents was also handled differently in the two surveys. To circumvent this difference, Statistics Canada also adjusted the published U.S. results to reflect responding firms instead of the number of firms sampled.

[6] Yves Fortier, "A Comparison of the Use of Advanced Manufacturing Technologies in Canada and the United States," *STI Review* 12 (Paris: OECD, 1993). For more information on how technology use is measured, refer to Louis Marc Ducharme and Fred Gault, "Surveys of Advanced Manufacturing Technologies," *Science and Public Policy* 19 (6) [1992].

**Table 1 — Use of at Least One Technology, by Industry, Canada and the U.S.**

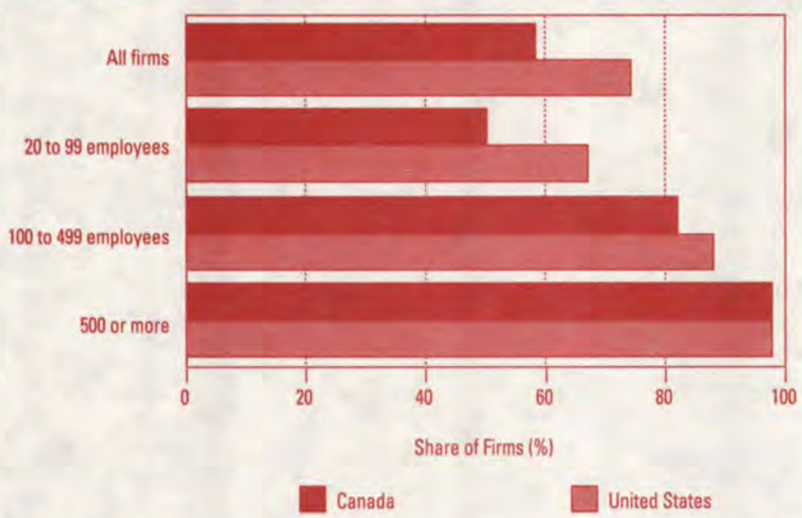
| | Canada 1989 | United States 1988 |
|---|---|---|
| | (percentage of establishments) | |
| All establishments | 58 | 74 |
| Fabricated metal products | 51 | 64 |
| Instruments and related products | 54 | 77 |
| Transport equipment | 51 | 69 |
| Industrial machinery and equipment | 73 | 82 |
| Electronic and other electrical equipment | 70 | 82 |

*Source:* See footnote 4, p. 62.

**Figure 4 — Intensity of Technology Use in Canada and the U.S. (percentage of establishments)**


*Source:* See footnote 4, p. 62.

**Figure 5 — Use of At Least One Advanced Technology, by Size of Firm**




*Source:* Statistics Canada, *Indicators of Science and Technology 1989*, vol. 1, no. 4, Catalogue No. 88-002, Chart 3.

## Size of Firms Is a Factor in AMT Use

Scale of operations is considered an important determinant in explaining AMT use, because of the greater ability of larger firms to absorb the associated costs of gathering information, purchasing, and training of personnel. The industries surveyed can be grouped into three sizes according to the employment of the firms: 20 to 99 employees, 100 to 499 employees, and 500 or more employees (see Figure 5). Based on these scale classifications, small and medium-sized firms in the U.S. appear more likely than their Canadian counterparts to use at least one AMT, whereas the largest firms in both countries are about equal in their adoption of at least one AMT.

This trend is also found in the analysis of the five industrial classifications (Table 2). The percentage difference between Canadian and U.S. firms in their use of AMTs generally narrows as scale increases, until there is little gap between the two in the largest scale classification.

The survey results indicate that U.S. firms in all size categories tend to use more AMTs than their Canadian counterparts. A lower proportion of U.S. firms in the two smallest scale classes employ no AMTs, and a higher proportion of U.S. firms in all size classes are found to employ five or more AMTs.

The Statistics Canada paper also compares the percentage of Canadian and U.S. firms employing technologies contained in five different technology classifications: computer-aided design/engineering, numerically controlled machines and computer numerically controlled machines, programmable controllers, computers for factory floor control, and local area networks for technical data. Survey results suggest a higher percentage of U.S. firms than Canadian firms employ each of the technology classifications, although they have the same relative level of importance in both countries. The Statistics Canada survey also collected information on the planned use of technologies. The results indicate that the same technologies show the strongest growth potential in both Canada and the U.S.

Studies in the resource sector show quantitatively but not qualitatively different patterns, since virtually all mines use at least one technology. As shown in Figure 6, mines employing over 250 employees use on average 15.5 advanced technologies, compared with small mines employing 1 to 49 employees, which averaged 2.2 AMTs.

## Characteristics of AMT Users

Researcher D. G. McFetridge[7] uses the data from the 1989 Statistics Canada survey to determine the characteristics of firms employing AMTs as well as the barriers to adoption that could be removed through public policy initiatives.

McFetridge's study tests seven firm characteristics or determinants, which are often cited as important in explaining the probability that firms will employ AMTs. The first of these determinants is the one considered in the Statistics Canada paper — establishment size or scale. The high costs associated with the acquisition of AMTs is believed to limit their use to those firms that have crossed the threshold where AMT use becomes economically viable.

McFetridge also tests the importance of multiple establishments as a determinant of the probability of AMT use. The inclusion of this hypothesis tests whether multiplant firms have an advantage over their single-plant competitors because of their ability to spread the costs associated with acquiring AMTs over all their plants, whether domestic or international. McFetridge also tests whether firms experiencing faster growth are more likely to employ AMTs as they more quickly reach the scale threshold. The other hypotheses tested by McFetridge include age of the plant, geographical location within Canada and technological opportunity.

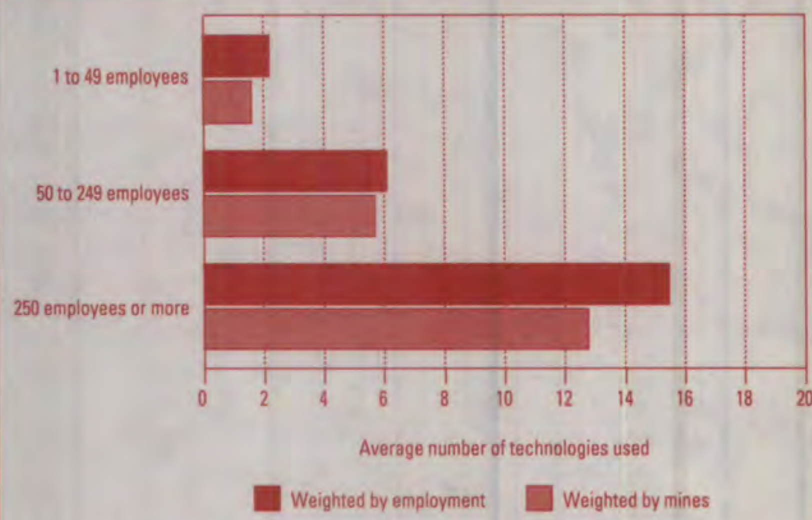
McFetridge tests the above hypotheses through regression analysis techniques by first pooling all firms contained in the 12 major industrial groups and also for each individual industrial group. The hypotheses are also tested for the following subsamples: metal and fabricating, non-electrical machinery, transportation equipment, electrical and electronic equipment industries, and also for selected major industries, namely wood and metal fabrication industries.

Table 2 — Use of at Least One AMT, by Employment Size and Industry, Canada and the U.S.

| | Number of employees | | | | | |
|---|---|---|---|---|---|---|
| | 20 to 99 | | 100 to 499 | | 500 or more | |
| | Canada | U.S. | Canada | U.S. | Canada | U.S. |
| | (percentage of establishments) | | | | | |
| Fabricated metal products | 43 | 57 | 79 | 87 | 99 | 97 |
| Instruments and related products | 43 | 69 | 93 | 89 | 99 | 99 |
| Transport equipment | 41 | 52 | 68 | 84 | 97 | 98 |
| Industrial machinery and equipment | 67 | 76 | 92 | 94 | 99 | 99 |
| Electronic and other electrical equipment | 60 | 72 | 87 | 89 | 94 | 98 |

*Source:* See footnote 4, p. 62.

Figure 6 — Average Number of Technologies Used, by Size of Mine




*Source:* See footnote 3, p. 61.

[7] D. G. McFetridge, *Analysis of Recent Evidence on the Use of Advanced Manufacturing Technologies in Canada,* Report prepared for the Economic Council of Canada (Ottawa: Supply and Services Canada, 1992).

## Importance of Scale

Scale is consistently found to be significant in each of the above samples in explaining the probability that firms will use AMTs. The industry-level results suggest that the importance of scale varies among the industries. AMT use varies between two and four times higher for firms with 500 or more employees than for firms with fewer than 100 employees. The only other determinant found consistently to be important in explaining the probability of AMT use is technological opportunity, as measured by the percentage of establishments in the same industrial sector that plan to use a given technology or group of technologies.

The importance of scale as a determinant of a firm's probability of using AMTs raises the question whether Canadian firms are too small to take advantage of the resultant benefits. McFetridge's results indicate that the scale threshold that firms must cross in order to make AMTs economically feasible may be as low as 100 employees.

## Multiplant Firms

One area where McFetridge's results have public policy implications concerns the rejection of the importance of multiplant establishments in explaining the probability that firms will employ AMTs. While it may seem evident that multiplant establishments are more likely to employ AMTs because they can share acquisition costs, the evidence rejects this. In combination with the demonstrated importance of plant scale, there may be two possibilities:

- because AMT acquisition costs vary from plant to plant, there exists no demonstration effect and consequently spillovers do not occur, or
- acquisition costs are high and are not plant-specific.

The implication of the first possibility, according to McFetridge, is that there is no basis for government intervention in the form of subsidies or tax credits to firms for adopting AMTs and facilitating the consequent demonstration effect. The implication of the second possibility suggests that single-plant establishments find alternative means to economize on the fixed acquisition costs. Opportunities to economize may include guidance from equipment suppliers, engineering consultants, non-profit technology centres, or by way of directly observing the practices of multiplant firms. If the firm receiving the information pays the appropriate level of compensation, there is no need for government intervention. If, however, the opposite is true, where free riders exist, public policy makers must determine the appropriate level of compensation to be paid to those from whom the information originates.

## AMTs in Canada and the U.S.

McFetridge's comparison of AMT usage rates in Canada and the U.S. echoes the results of the Statistics Canada study in that he finds Canadian usage to lag U.S. usage.[8] McFetridge explains this difference in terms of the small size of Canadian firms relative to their U.S. counterparts. Scale-adjustment calculations narrow the gap. Canadian firms continue to lag their U.S. counterparts in some size classes, all major groups and all technology classes. There also continues to be the lag within size classifications and within industrial groups. McFetridge hypothesizes that these differences may be due to three factors:

- Major industries in the two nations differ in composition. Adjustments for industrial mix and scale reduce the percentage difference between the two countries in AMT use.
- There exists a large defence component in the U.S. economy, where firms have a greater likelihood of using AMTs. Adjustment for this difference reduces but does not eliminate the gap.

[8] McFetridge's results are based on unweighed averages of percentage of AMT use by technological and industrial classification.

- Firms in Canada and the U.S. are predominantly involved in different stages of the manufacturing process. The U.S. firms may be involved in a stage of manufacturing that is more conducive to use of AMTs, such as fabrication, than another stage, such as assembly.

McFetridge's results are summarized below.

**Significant factors in AMT usage:**

- Establishment scale: Larger establishments are more likely to use AMTs. Size is the most important variable influencing AMT adoption.
- Industrial sector: For a given size, the greater the proportion of other firms using AMTs in a sector, the more likely a subject firm will use it.
- Region: Regional factors, including regional government S&T policies and educational facilities, influence the adoption of AMTs, but this factor is not as important as the first two.

**Factors that are not significant:**

- age of the manufacturing establishment
- multiplant versus single plant enterprises
- nationality of controlling interest.

## Conclusion

The fact that U.S. plants generally have a higher usage of AMTs is borne out in productivity measurements. This has competitiveness implications for Canadian industry. In general, it is likely that Canadian firms will have to match the productivity (and hence the use of AMTs) of their American competitors if they are going to maintain or increase their share in their sector of the North American market. The measured lower penetration of particular technologies may be a statistical anomaly resulting from the lower average size of Canadian firms within each size classification.

McFetridge demonstrates that use of a specific AMT is pervasive in any given industrial sector. Canadian firms have to ensure that they have state-of-the-art production equipment in order to compete in the global economy. Foreign as well as Canadian innovations in production technologies have to be acquired and used in Canada. Like the Red Queen in Lewis Carroll's *Alice Through the Looking Glass,* all Canadian industrial sectors have to run as hard as they can just to stay where they are.

But a ray of hope exists. The threshold (size of establishment) at which AMT use becomes cost-effective is not high. Canadian firms need to be able to adapt their smaller size relative to American firms (a competitive advantage when it comes to flexible manufacturing) through the use of AMTs into a competitive advantage in itself.

# The National Advisory Board on Science and Technology*

The National Advisory Board on Science and Technology (NABST) was created in 1987 to provide the Prime Minister with expert, non-partisan advice on national science and technology (S&T) goals and policies and their application to the Canadian economy.

NABST was first given broad mandates to assess and report on approaches to S&T by government, university and industry sectors in Canada. Later work programs focused on critical issues identified by the board, which were assigned to working committees and became the subjects of committee reports submitted subsequently to the Prime Minister. A total of 25 reports have been published to date (August 1994), containing over 150 recommendations; a further four are forthcoming.

In addition to recommendations, NABST reports have provided new approaches and critical information regarding the structure of the Canadian S&T establishment, its performance, constraints to improvements in that performance and patterns in the allocation of national financial and human resources.

The board has also been active in building linkages with advisory councils in other jurisdictions, holding joint meetings with provincial Premiers' Councils, the U.S. President's Council of Advisors on Science and Technology (PCAST) and the Japanese Prime Minister's Council on Science and Technology (CST). These linkages have helped the board to identify new approaches and best practices in S&T policies and programs.

## NABST Work Programs and Statements to Date

### 1987–91

The views NABST developed over its first four years on the relationship between S&T, innovation and competitiveness were contained in the board's 1991 *Statement on Competitiveness.* Through 17 separate studies, NABST had determined that it was urgent for Canada to deal with the competitiveness challenge of global markets. This result reaffirmed the motives for NABST's creation in 1987: to put S&T and a commitment to international competitiveness at the top of the government's agenda.

### 1991–94

The work program for the next two and a half years began by dealing with some of the results of NABST's initial recommendations. The Prosperity Initiative, which followed NABST's *Statement on Competitiveness*, generated hundreds of S&T proposals, which were reviewed by the NABST Committee on Competitiveness. A second committee studied the Competitiveness of the Resource Industries in greater depth. A third NABST initiative, which became a crucial element of the board's agenda for the balance of its term, examined federal S&T priorities and recommended a new approach to achieving more effective allocation of government expenditures on S&T in an environment of increasing fiscal restraint.

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* This article was prepared by the NABST Secretariat.

After further study of aspects of human resource development, NABST made recommendations in 1992 and 1993 regarding the inadequately realized potential of women and of immigrants to play significant roles in a Canadian work force where skills depend increasingly on an S&T base. Its 1993 report "Winning with Women" presented an action plan to encourage women's participation in S&T fields. NABST expects to make further recommendations in 1994 on the question of national standards in education and their role in making the best use of Canada's human potential.

The government's role in strengthening industrial capability, particularly in facilitating the acquisition and application of new technologies, was reviewed by the NABST committees on Federal Government Procurement and on Technology Acquisition and Diffusion, which submitted their recommendations in 1992 and 1993. The reports' recommendations highlighted the value of linkages among the S&T community, government, industry, banks, industry associations and other supporting organizations, as instruments to enhance industry's adoption and application of S&T to drive economic growth. A third committee on Canada's role in International S&T is investigating how well Canada facilitates firms' access to foreign technology.

Reports and recommendations in relation to government S&T strategy in two natural resource areas — Energy Efficiency and Oceans and Coasts — are expected in September 1994.

## NABST Publications

All of the following publications may be obtained from:

NABST Secretariat
Industry Canada
8th Floor, West Tower
235 Queen Street
OTTAWA, Ont.
K1A 0H5
Tel.: (613) 990-6260
Fax: (613) 990-2007

**1988**

Government Committee Report on InnovAction (February)

Government Committee Report (February)

Industry Committee Report (February)

University Committee Report (February)

Government Procurement Committee Report (February)

Participation of Women in Science and Technology Committee Report (February)

Department of Industry, Science and Technology Committee Report (February)

Public Awareness Committee Report (February)

Economic Summit Proposal Committee Report (February)

**1989**

Big Science Committee Report (May)

Keeping Canada Competitive: The Innovation Imperative: A Report of the Private Sector Challenge Committee (May)

**1990**

Revitalizing Science and Technology in the Government of Canada: A Report of the Committee on Federal Science and Technology Expenditures (November)

**1991**

Statement on Competitiveness (March)

Science and Technology, Innovation and National Prosperity: The Need for Canada to Change Course (April)

Learning to Win: Education, Training and National Prosperity: A Report of the Human Resource Development Committee (April)

Financing of Industrial Innovation Committee Report (March)

Big Science Committee Report on the KAON Project (October)

**1992**

Federal Government Procurement (March)

Report of the Competitiveness Committee (September)

**1993**

Measuring up to the Benchmark and Moving Ahead: A Report of the Committee on Technology Acquisition and Diffusion (September)

Winning with Women in Trades, Technology, Science, and Engineering: A Report of the Human Resource Development Committee (January)

Committee on the Competitiveness of the Resource Industries (May)

Immigration of Scientists, Engineers, Technicians and Technologists (December)

Spending Smarter: First Report of the Committee on Federal Science and Technology Priorities (June)

**1994**

Spending Smarter: Second Report of the Committee on Federal Science and Technology Priorities (February)

International S&T (in press)

Energy Efficiency (in press)

Oceans and Coasts (in press)

National Standards in Education (in press)

# National S&T Governance Profiles*

These science and technology (S&T) governance profiles are short descriptions of the approaches taken by governments of selected countries to the development and management of S&T.

## Structures

While S&T is a high priority for all industrialized nations, approaches to its national governance vary. S&T is affected by global trends such as the spread of information technology and changes to the organization of research itself. However, economic infrastructure and national traditions play an equally important role in shaping how S&T is harnessed for domestic needs.

As the strategic importance of S&T grows, governments of all industrialized countries are refining and restructuring institutions and initiatives to improve the management of government S&T expenditures and performance. In policy, as in scientific research, there is a need for experimentation, flexibility and diversity of approaches in developing innovative lines for S&T policy.

As different countries have attempted to respond to similar S&T-related issues, there has been a strong structural convergence in national systems of S&T governance.

The majority of modern national S&T governance systems usually include a central organization or ministry with the responsibility for setting overall government S&T policy. Frequently, there is also a broadly drawn expert advisory group representing the various interests of the national science and innovation community.

## Priorities

All national S&T systems are increasing emphasis on technology transfer, innovation and strengthening of their industrial technology base.

Other key national priorities include strengthening the domestic S&T infrastructure, improving the S&T education system and strengthening public knowledge of S&T.

International S&T collaboration is becoming more important. The governments of the most industrialized nations are increasing their efforts to promote international industrial R&D collaboration. They attach a lot of importance to ensuring that their domestic private sector gains full access to international R&D opportunities.

Recognizing the importance of a strong basic research infrastructure, most governments have devised systems to allocate funds to science on the basis of peer review, with minimal involvement of government administrative bodies. Direct government involvement in science is usually limited to funding and organizing their scientists' participation in large, internationally funded science projects and to encouraging links between the private and public sectors that promote research partnerships.

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* Material for these profiles was collected by Canadian embassy staff in each country, and the summaries were prepared by the International Science and Technology Directorate of Industry Canada.

# AUSTRALIA

| Statistical Overview (1990) | |
|---|---|
| GERD (A$ millions) | 5 091 (C$5 255 million) |
| GERD/capita (A$) | 298 (C$307) |
| GERD/GDP (%) | 1.34 |
| GERD by source (%): | |
| Government | 54.9 |
| Industry | 40.3 |

### S&T Policies/Objectives

Australia, like Canada, does not appear to have a centralized S&T expenditure management system. It does have centres of S&T policy advice and coordination, and the Minister for Industry, Science and Technology produces an annual budget statement for S&T.

In 1992, the Australian government issued a White Paper on S&T titled *Developing Australian Ideas: A Blueprint for the 1990s*. This document focuses on four interrelated themes: innovation, awareness, skills and infrastructure. The improvement of cooperation between the funders, performers and users of research and the more effective application of research findings for the country's economic and social well-being are assigned high priorities. There is a commitment to look for a better commercial return on publicly funded research. A key decision will be to continue the tax concession for industrial research and development (R&D) at 150 percent indefinitely.

### Institutional Organization

In 1992, the Australian government redefined the role of the Prime Minister's Science Council, renaming it the Prime Minister's Science and Engineering Council (PMSEC). The PMSEC, chaired by the Prime Minister, with the Minister for S&T as Deputy Chair, consists of senior ministers with strong portfolio interests in S&T matters and leading figures from the S&T community. The Chief Scientist is the executive officer. The PMSEC has published reports by independent expert groups on matters such as climate change and biodiversity, the changing manufacturing technology, and on opportunities and strategies for Australia's S&T in the Asia-Pacific Region.

The Coordination Committee on S&T, consisting of senior representatives of ministries and agencies, has a complementary role to PMSEC. The Coordination Committee recently reviewed mechanisms used to set S&T priorities announced in the 1992 White Paper. The report stressed that priority setting by Australian Commonwealth agencies needs to reflect the outcomes of a dialogue between users and researchers and the need for a user-driven focus.

The Australian S&T Council (ASTEC) is the government's principal source of independent policy advice. Following the recommendations of a review committee, ASTEC will increase its emphasis on application of S&T, particularly to industrial needs. ASTEC has a Committee on the Future Needs of Science in Australia, which will perform research foresight exercises to help identify key research areas for Australia's future. The Department of Industry, Science and Technology (DIST) has a broad responsibility for S&T, although a number of other departments also have strong interests.

Public funding of research in the public and private sectors has recently been the object of inquiry by the Joint Committee of Public Accounts, which involved widespread consultation with interested groups across Australia. The committee's first report considered general issues including national priorities, human resources, infrastructure, market failures, and research management and commercialization within Australia's public research agencies. The second report considered support for R&D in the private sector, including issues such as taxation, capital, intellectual property rights, and grants and other assistance programs.

Other government institutions include the Australian Research Council, which advises on research policy and distributes research grants on a nationally competitive basis. The government also has several major independent research agencies and has encouraged increased links between these research organizations and industry through external funding targets. To encourage a focus on strategic research for industry when setting priorities, the agencies are permitted to retain their earnings; funding is on a triennial basis in recognition of the long-term nature of research.

#### Areas of Strategic Expenditure

Strategic areas of R&D expenditures include:

- Special Research Centres, which support fundamental strategic research
- Key Centres for Teaching and Research, which are closely linked to the needs of industry and society
- Co-operative Research Centres, which conduct federally funded research programs involving collaboration between educational establishments and industry with DIST as the responsible department.

Other programs include the 150-percent tax concession scheme for industrial R&D, Grants for Industry Research and Development Scheme, a National Procurement Development Program, an Advanced Manufacturing Technology Development Program and Advanced Engineering Centres.

## AUSTRIA

| Statistical Overview (1990) | |
|---|---|
| GERD (schilling, millions) | 31 297 (C$2 771 million) |
| GERD/capita (schilling) | 4 003 (C$351) |
| GERD/GDP (%) | 1.54 |
| GERD by source (%): | |
| Government | 46.0 |
| Industry | 50.9 |

#### S&T Policies/Objectives

The basic S&T objectives of the Austrian government, which were articulated in the 1981 Research Development Law are:

- broadening and deepening the scientific base
- solving key economic, social, cultural and scientific problems, particularly as they pertain to economic development and improvement in the quality of life
- rapid commercialization of the results of scientific R&D
- developing a new generation of scientists.

The key S&T policy-making body is the Ministry of Science and Technology. Its key present policy thrust is to ensure effective exploitation by Austrian businesses and research organizations of opportunities offered by the European Union's (EU) S&T programs. Austria promotes close collaboration between basic research and industry, looking for research synergies within the EU in technology areas such as advanced materials and space science.

#### Institutional Organization

Three key ministries are directly involved in the development of S&T policies and the delivery of S&T-related programs. As indicated above, the most influential in policy making is the Ministry of Science and Technology. The other two are the Ministry of the Economy and the Ministry of Public Economy and Transport.

The Ministry of Science and Technology has an Advisory Council, drawn from a variety of scientific and other specialties and appointed for a four-year term. Officials of the ministry sit on all subcommittees of the Advisory Council and support their work. The ministry makes an annual report to Parliament on the present state and future developments of Austria's S&T policies and expenditure programs.

Another key player in S&T is the Office of the Chancellor. The office maintains a data bank that registers all state support for S&T. The Chancellor is likely to be involved in all key expenditure decisions, including S&T-related expenditures.

A Bureau of Technology Information has been set up in Brussels, Belgium, to assist Austrian businesses and research organizations in obtaining information about EU Framework Programmes and other programs, sourcing funds, and serving as a matchmaker and interface between Austrian and international R&D organizations. The bureau is funded by a number of Austrian public and private organizations, including the Ministry of S&T, the Federal Chamber of Commerce and the Association of Austrian Industrialists.

Another key Austrian S&T organization is the Federal Economic Chamber, which is actively participating in international technology programs. The Federal Economic Chamber cooperates closely with three Technology Counsellors in New York, Los Angeles and Tokyo. It also relies on Austria's extensive trade commissioner network in some 86 centres worldwide for extensive detailed reporting and follow-up on technology development opportunities. The network will also support business requests for assistance to access international technology opportunities.

### Areas of Strategic Expenditure

The key federal industrial R&D support program is the Austrian Industrial Research Promotion Fund. In 1993, the fund allocated the equivalent of C$200 million to 702 projects, leveraging an additional C$600 million from industry participants. Chief areas of activity were microelectronics and environmental technologies. Other research projects involved medical technologies, computer simulations of complex technical processes, laser technologies, advanced materials and biotechnology. More than 80 percent of these projects involved small or medium-sized businesses (fewer than 500 employees).

## THE EUROPEAN UNION

| Statistical Overview (1994) | |
|---|---|
| Fourth Framework Programme (1994 to 1998) | 11.0 billion ECUs (C$17.5 billion) |

### S&T Policies/Objectives

Under Article 130i of the European Community treaty, a multiannual framework program that sets out all the R&D activities of the European Community, is adopted by the Council of Ministers in co-decision with the European Parliament and in consultation with the Economic and Social Committee. The Fourth Framework Programme, which will run from 1994 to 1998, will distribute a total of 11.0 billion ECUs (C$17.5 billion) in support of collaborative R&D projects by research organizations and businesses from member countries.

The broad aims of the European Union's industrial innovation and research policies are to increase competitiveness of European firms and intra-European industrial collaboration, enhance the technological independence of Europe in strategic technologies and promote the dissemination of new technologies and innovations to enterprises. The EU R&D expenditure is less than 4 percent of member states' government expenditure on civil R&D.

### Institutional Organization

The European Commission delivers the EU's R&D programs, through a series of overlapping R&D Framework Programmes (FPs). Atomic energy research is conducted by EURATOM. Primary responsibilities for R&D fall under two commissioners supported by directorates general: Vice-President, Research, Education and Training (DG XII — Science, Research and Development); and Vice-President, Industry and Telecommunications (DG XIII — Telecommunications, Information Market and Exploitation of Research). In addition, the Joint Research Centre of the commission, with some 2 300 researchers at four sites, performs scientific research and technology development for the European Commission, national agencies, universities and corporate clients.

As set by the Maastricht Treaty in 1992, the process for the FPs is lengthy and complex. In brief, the commission proposes, Parliament approves or rejects, and the Council of Ministers adopts. The sequence of interactions of these three players varies as the FP moves through three stages from initial proposal to final program.

The FPs were established in 1984 as a means to bring about coordinated research in the EC to combat the diminishing competitiveness in Europe's high-tech industries, the lack of investment in industrial research and the inability of firms to translate S&T excellence into commercial success. European Community programs such as ESPRIT (information technologies) and BRITE (advanced materials and manufacturing technologies), have produced commercial results on about half of 2 000 projects over the past eight years. European research efforts have brought about one key benefit: the creation of a pan-European industrial research community.

EU support for technology creation is divided between the FPs and other related programs outside the FP that cover education, pilot and demonstration projects, and coal and steel research —approximately 2 billion ECUs (C$3 billion). The FPs focus on precompetitive, prenormative or generic R&D. Competing consortia of firms, universities and government institutes in the member states submit proposals. Participants must be from two or more member states, including member countries of the European Free Trade Area who, via the European Economic Area, have joined as full program participants. Participants from non-European nations are permitted only if their country had an access treaty with the European Community. Australia completed such negotiations in 1992.

#### Areas of Strategic Expenditure

The R&D research areas are:

- information and communication — 3.4 billion ECUs (C$5.4 billion)
- industrial technologies — 1.9 billion ECUs (C$3 billion)
- environment — 1.1 billion ECUs (C$1.75 billion)
- life sciences and technology — 1.6 billion ECUs (C$2.5 billion)
- non-nuclear energy — 1 billion ECUs (C$1.6 billion)
- transport systems — 240 million ECUs (C$400 million)
- socio-economic research — 138 million ECUs (C$200 million).

The EU allocates 540 million ECUs (C$860 million) to third-country cooperation with non-Community countries and organizations. Some 330 million ECUs (C$525 million) are devoted to improving the dissemination and use of research results, transfer of technology, financing transfer and providing scientific services for Community policies. This includes a fund to provide interest rate subsidies, guarantee loans, measures to encourage venture capital, and managerial and technical assistance. Expenditures of 744 million ECUs (C$1.2 billion) stimulate the training/mobility of researchers to strengthen European industry.

The European Commission supports innovation and technology transfer as well as regional promotion of technological infrastructure through programs such as VALUE (dissemination of R&D results), SPRINT (integrating national innovation infrastructures), STAR (the Special Telecommunications Action for Regional Development), STRIDE (The Science and Technology for Regional Innovation and Development in Europe) and Valoren (energy conservation).

S&T cooperation between Canada and the EU is through the 1976 Industrial Cooperation Agreement. Canada is negotiating a treaty to gain access to R&D opportunities under the fourth FP. As of 1992, Canada had a total of 13 bilateral S&T arrangements with the EU.

## FRANCE

| Statistical Overview (1992) | |
|---|---|
| GERD (francs, millions) | 164 621 (C$40 875 million) |
| GERD/capita (francs) | 2 695 (C$554) |
| GERD/GDP (%) | 2.36 |
| GERD by source (%): | |
| Government | 48.8 |
| Industry | 42.5 |

#### S&T Policies/Objectives

Government funding of S&T is controlled by the Ministry of Research and Higher Education. The Ministry of Defence accounts for over half the public funding.

In June 1993, in an effort to develop a new national science and research strategy, the French government launched a multistage consultation process on major objectives for French research. To set the agenda for this consultation, a 78-page discussion paper, *The Main Objectives of French Research*, was prepared by a group of scientists, university presidents and government officials. The paper was circulated to a group of representatives of the S&T community for comments, before being finalized and distributed to over 60 000 French scientists in January 1994.

A series of seven regional roundtables was held over a six-week period in February and March to discuss basic themes: science and society; research, technology and industry; fundamental research; training in higher education; work structures and careers; research and innovation in small and medium-sized enterprises; and international collaboration in research. A national conference was held in Paris on 18 April 1994.

This consultation process concluded in a parliamentary debate in June 1994 (following its approval in the Senate), during which recommendations were put forward by the government for action on the directions that French S&T research is to take in the coming years. A framework bill will be presented to Parliament in November 1994. In order to follow-up on the implementation of this plan, the government will be establishing a Strategic Orientation Committee for research. One of the measures proposed in this plan is to increase the French national gross domestic expenditure on research and development (GERD) from 2.4 percent of gross domestic product to 2.9 percent by the year 2005. This will require a substantially increased effort in industrial R&D, promotion of major technological programs in the public and private sectors, an increased technological effort from universities, an enhanced partnership/dialogue between public research organizations and private sector counterparts.

#### Institutional Organization

The Ministry of Research and Higher Education has overall authority over civilian research carried out by most of the major public research organizations and agencies, including research in the universities. In 1993, the ministry was expanded to include those responsibilities formerly held by the Ministry of Research and Space. This was expected to increase cooperation between universities and public research institutions. The ministry is represented on all interministerial research planning committees and is consulted on priorities, key programs, regional activities and other issues impacting on industry. The Finance Ministry is also represented on interministerial committees, with the result that budget problems are often resolved before decisions are taken at Cabinet level. Industry is the responsibility of the Ministry of Industry, Post, Telecommunications and Tourism.

A council nominated by the Minister of Research and Higher Education, the Conseil de la Recherche Scientifique et Technique (CRST) advises on the overall impacts of science policy. Its 40 members include representatives from industry, academia and government. The CRST has set up five working groups covering problems of validation, research and transfer of technology, employment and science, regional problems, and financing of research. The Parliamentary Office for Scientific and Technological Choices, which is modelled on the U.S. Office of Technology Assessment, is designed to provide analytical work on key technology policy issues for more informed debate in Parliament.

The Ministry of Research and Higher Education administers the funding of the government's main research programs in S&T. It also collects information on 5 800 universities and 1 700 laboratories in the public sector. This is intended as the basis of a comprehensive national data base on S&T. Like the recent German exercise, the French government, through the Ministry of Research and Higher Education, and the Ministry of Industry, has undertaken a massive survey (Delphi technique) of future technologies and where France should seize emerging opportunities. The results of this survey will be assessed in the coming months.

The government's civilian research budget of 53 billion French francs (C$13.5 billion) for 1994 is divided among the main research agencies, public scientific and technological institutes, and public industrial and commercial establishments. The defence R&D budget is completely separate from the civilian budget and amounted to 30 billion French francs (C$7.6 billion) in 1994.

France has 20 governmental research agencies. The most important institutes are the National Centre for Scientific Research, the National Centre for Space Studies, the Commission for Atomic Energy, the National Institute for Medical Research and Health, and the National Agency for the Promotion of Innovation. In addition, France will contribute about 5 billion French francs in 1995 to the Fourth Framework Programme for R&D of the European Union.

Other agencies and ministries involved in financing French research include the Ministry of Defence, the Ministry of Industrial Redeployment and Foreign Trade, and the Prime Minister's Planning Office.

The primary S&T policy function of the Prime Minister's Planning Office is to determine lines of research and to initiate and subsidize research in units attached to it. It is concerned with the social consequences of adopted or planned government policies. The office has several units, including a global economic intelligence unit, concerned with economic analysis and planning. A second organization is concerned specifically with changes in industry patterns worldwide. A unit monitoring economic trends and the Institute for Economic and Social Research are also funded by the Prime Minister's planning budget.

Also responsible for collecting and publishing annual statistics on S&T is the Observatoire des sciences et des technologies (analogous to the role played by the National Science Board in the United States in publishing its Science and Engineering Indicators).

### Areas of Strategic Expenditure

Government priorities include support for key programs in S&T (in such areas as biotechnology, computer software and audio-visual technology), regional development and collaboration, technology transfer and strengthening the technology base of small and medium-sized businesses. Advanced training for research and ensuring that the results of R&D respond to market requirements is also emphasized by France's S&T policy. Other priorities include the mobility of researchers between public institutions and industry, technology development, training of qualified scientists and engineers in the regions, conservation and new sources of energy, and programs concerned with the impact of technology on society, education, employment and labour conditions.

In an attempt to decentralize technology development in the early 1980s, France began establishing technology parks called technopoles, which are modelled on similar centres in the United States such as Silicon Valley and the Research Training Park in North Carolina. Like other technology parks, the technopoles serve as incubators for start-up companies, but include a high degree of government support not found in other countries. The various levels of French government provide about 75 percent of the technopoles' financing. While the Centres régionaux d'innovation et de transfert de technologie are responsible for technology diffusion into the regions, the regions play a marginal role in defining the overall S&T strategy.

## GERMANY

| Statistical Overview (1992) | |
|---|---|
| GERD (marks, millions) | 77 590 (C$65 812 million) |
| GERD/capita (marks) | 951 (C$570) |
| GERD/GDP (%) | 2.58 |
| GERD by source (%): | |
| Government | 37.0 |
| Industry | 59.9 |

### S&T Policies/Objectives

The defining characteristic of public research support in Germany is its federal structure: each Laender (or state) has an S&T policy of its own. At the national level, the Bundesministerium für Forschung und Technologie (BMFT) is responsible for more than half of the total government research budget.

The main S&T objectives of the German government are to:

- encourage economic growth and job creation through competitive products and services with stringent adherence to good ecological practices
- maintain Germany as an important and attractive location for industry, services and R&D in a merging Europe
- establish an efficient research environment in the new German Laender by reorganizing existing research institutions and setting up of new ones.

In spring 1993, a comprehensive policy paper, *Standort Deutschland*, was released. The paper dealt with international competitiveness of German industries and innovation. Although it is one of the most technologically advanced countries, Germany has been slower to turn the products of research into wealth-creating products than its primary competitors — the United States and Japan. Consequently, the government has shifted its policy toward increasing the efficiency with which research results are transferred out of the laboratory into industry. It is pursuing improvements in cooperation and strategic dialogue between government, researchers and industry; improved evaluation procedures in research funding competitions; more support for "bottom-up" initiatives; and more input of research policy in the public debate on technology and jobs.

*Technologies for the 21st Century* was released by the BMFT in September 1993. It identifies 87 critical technologies for the next 10 years and notes trends toward integration of previously separate branches of research and knowledge.

The German S&T management system is highly decentralized. Departments and agencies manage their own S&T budgets. For example, the German Space Agency, nominally under the S&T ministry (the BMFT), is managed autonomously.

### Institutional Organization

Principal performers of R&D in Germany are industry, the universities and four non-university research organizations:

- the large National Research Centres (each focused on basic research in a specific discipline)
- the Fraunhofer Society for Applied Research (which supports applied, industry-oriented R&D institutes across Germany)
- the Max Planck Society (which supports scientific research institutes)
- the "Blue List" research institutes (organizations dedicated to basic research in specific disciplines).

The German Research Society is a granting agency, which supports university research with an annual budget of DM 1.6 billion (C$1.4 billion).

After reunification, the Academy of Sciences of the former East Germany was dissolved following extensive evaluation of its research institutions. On the basis of this evaluation, the German Science Council drew up recommendations which, in 1992, led to the setting up of:

- three new national research centres
- 24 new "Blue List" research institutes
- 21 institutions and working groups of the Fraunhofer Society
- two institutes and 28 working groups of the Max Planck Society.

In summer 1993, the Research Minister set up a technology council made up of 12 representatives from industry and the scientific community to advise him on developing a more coordinated and responsive research strategy. One recommendation of the council was that the Research Minister should have broader responsibilities, particularly more control over the total government research budget. At present, this responsibility is divided among four ministries.

Responsibility for research promotion is divided between the federal government and the Laender governments. The Laender governments fund academic research and science in the universities, technical universities and practice-oriented Fachhochshulen (post-secondary polytechnic-like institutions). Federal and Laender governments jointly operate non-university research institutions, such as the scientific research-oriented Max Planck Society, the industrial research-oriented Fraunhofer Society, the national research centres and the Blue List basic research institutes. Contributions to international research institutions are the responsibility of the federal government.

The German Science Council is the most important dedicated permanent S&T advisory body in Germany. Its mandate is to provide advice to both the federal president and to Laender governments. The Science Council distinguished itself when it carried out the tricky task of reviewing the S&T infrastructure and capabilities of the former East Germany, making strong recommendations on its restructuring to make it compatible with West German organization, practice and quality standards.

### Areas of Strategic Expenditure

Current strategic programs being undertaken by the BMFT include the materials research program, the biotechnology 2000 program, the federal government framework program on the future of information technology and promotion for information technology. These programs each consist of several initiatives, which are updated at regular intervals.

Germany supports strategic, internationally oriented long-term S&T programs such as fusion research, marine research, polar research and space research. Areas of interest in basic research include large-scale equipment for basic physics research, namely two new particle accelerators. Other investments include astronomy, research vessels, continental deep drilling, research reactors and synchrotron radiation sources.

The university renewal program of the federal government and the new Laender is helping to rebuild the staff, departments and infrastructure of the higher education institutions of the former East Germany. This program is bringing scientists of the former Academy of Sciences back to the universities, renewing academic staff, reforming subjects and departments, supporting young scientists and providing adequate equipment for universities.

## ITALY

| Statistical Overview (1992) | |
|---|---|
| GERD (lira, millions) | 20 847 061 (C$17 683 million) |
| GERD/capita (lira) | 360 785 (C$306) |
| GERD/GDP (%) | 1.38 |
| GERD by source (%): | |
| Government | 48.3 |
| Industry | 42.5 |

### S&T Policies/Objectives

The current Italian government has not yet addressed the present decentralized and bureaucratic system of managing R&D expenditures.

Each year, the president of the National Research Council presents a report on the situation of Italian S&T to the Committee of Ministers for Economic Programs. The 1994–96 Triennial Plan for Research and Innovation Development, presented to Parliament as part of budget discussions, contains the proposals for annual or multi-annual programs to be carried out by the various research agencies. The National Consultative Committees, responsible for specific fields of S&T, provide policy advice.

### Institutional Organization

The Committee of Ministers for Economic Programs controls research funding; its secretariat role is the responsibility of the Ministry of the Budget. The National Research Council is the largest of the public sector research bodies with more than 250 component organizations, of which about 40 percent are in universities. It provides advice to other organizations about scientific issues, manages and coordinates scientific research, establishes standards for equipment and materials used by scientific organizations, and participates in the formulation of science policy by advising the government.

Established in 1989, the Ministry for Universities and Scientific and Technological Research is responsible for coordination and planning. The ministry does not provide funding, which is the responsibility of independent research institutions and universities.

Other government bodies involved in S&T are the National University Council, an elected body of academics that provides advice to the minister responsible for university research programs: the Ministry of Industry, the National Commission for Nuclear and Alternative Energy Sources, the National Institute of Nuclear Physics, the Italian Space Agency, the Central Institute for Statistics and the Higher Institute for Health.

In December 1993, the Ministry for Universities and Scientific and Technological Research announced plans to scrap the country's much-criticized system of distributing research funds through small committees, and to introduce a formal peer-review process for almost all government-funded research. Discussions have begun between the ministry and Italian industry to identify long-term strategic research needs.

The state plays a bigger role in research planning than in most member countries of the Organisation for Economic Co-operation and Development (OECD), and the most common complaint is excessive bureaucracy. This year, in line with reforms set in motion by the former Universities and Research Minister (who is now European Union Education Commissioner), universities will be handed control over their own budgets, which will require them to prioritize spending. In the new system, a university's base-line funding could be affected by the ministry's assessment of its efficiency, including its research performance. This reform is expected to encourage stronger ties between universities and industry, which are weak compared with those of the rest of northern Europe.

### Areas of Strategic Expenditure

Priority areas of R&D, designated as strategic by the government, include robotics; environmental technologies; informatics, nanotechnology and information technology; environment and town planning; advanced biological technologies; chemical and physical aspects of biological systems; advanced technologies; infrastructure; and services and cultural issues.

Nine consortia were set up by the National Research Council in the 1980s to help transfer innovative technology from universities to industry. These help industry to obtain assistance from university researchers.

## JAPAN

| Statistical Overview (1992) | | |
|---|---|---|
| GERD (yen, millions) | 13 909 493 | (C$92 501 million) |
| GERD/capita (yen) | 111 862 | (C$742) |
| GERD/GDP (%) | 2.87 | |
| GERD by source (%): | | |
| Government | 18.2 | |
| Industry | 72.7 | |

### S&T Policies/Objectives

The Japanese government has three fundamental S&T-related goals: the need for humans to coexist with nature; the need to expand intellectual stock; and the need to improve the social quality of life (officially stated as the construction of a charming society where people can live with peace of mind).

The Prime Minister's Council for Science and Technology (CST) is the key S&T policy body in Japan. Chaired by the Prime Minister, the council reports and gives advice on S&T policy, establishment of long-term R&D goals and initiatives necessary to achieve these goals. In cooperation with the Ministry of Finance and the Science and Technology Agency, the Policy Committee of the Council for Science and Technology sets out guidelines and decides upon the R&D budget requirements for individual ministries and agencies based on annual submissions from each ministry and agency.

In January 1992, the CST put forward proposals for a new organization for S&T policy under the title *Comprehensive and Basic Science and Technology Policy toward the New Century*. Following the CST recommendations, the Japanese government established the Basic Policy for Science and Technology at a meeting of the Cabinet in April 1992. Its objectives were to:

- increase R&D investment in key areas of advanced technology
- reduce dependence on foreign energy by developing new energy sources (principally nuclear) and by eliminating waste
- reduce dependence on foreign raw materials by the exploitation of ocean resources and by moving toward smaller high-tech products that require less raw materials
- improve innovative capability by improving cooperation among industry, government and the universities, by breaking down interdisciplinary barriers and by more emphasis on basic research
- improve the quality and development of regional S&T
- increase international S&T collaboration
- ensure adequate supply of highly qualified trained personnel.

### Institutional Organization

The CST exercises general control over the government's S&T policies. Advice on all aspects of science is received from the Science Council of Japan, an independent body of scientists. The Science and Technology Agency (STA) is responsible for overall coordination of science policy among the different government ministries and agencies. STA serves as a secretariat for the various commissions attached to the CST and, through its attached research institutes, is responsible for the big science projects supported by government funding. Research institutes are attached to each of the ministries and agencies carrying out R&D; some ministries are also linked to special research corporations such as the Research Development Corporation of Japan, which promotes industrial exploitation of basic research carried out in Japan and which manages STA's program of research fellowships aimed at bringing young foreign researchers into Japanese national laboratories.

The Ministry of International Trade and Industry, particularly its Agency of Industrial S&T, has key responsibilities for promoting linkages between government R&D activities and the national industrial policy. The Ministry of Education, Science and Culture, especially its bureau of Higher Education and of Science and International Affairs, also has a strong interest in S&T policy.

The S&T policy-making process is as follows. Each year, before the national budget is finalized, key issues are identified by the Policy Committee of the CST as "Important Guidelines for S&T Promotion." These guidelines represent the CST's annual direction prior to the submission of the individual ministries' budget requirements. Individual ministries request S&T funding within these guidelines for programs for S&T promotion. In order to select key issues for each year, the Policy Committee of the CST collects S&T policy information by canvassing the individual requirements of the ministries, as well as of the business community. The committee then decides upon the budget requirements on the basis of information it collected and expert opinions of the committee members.

The CST holds hearings on the requirements of the individual ministries' S&T plans prepared annually in response to the guidelines mentioned above. Funding is allocated on a priority basis. Priorities are based on the analysis performed by the Research Investigation Subcommittee of the Policy Committee of the CST.

Within the Diet, there are many committees that lobby for various interests and causes. There is one for Science and Technology, which includes 25 members of the House of Representatives and 20 members from the House of Councillors. The Diet S&T Committee has addressed S&T-related issues, including the development of Japan's indigenous satellite launch capability (the H-2 rocket) and the dilapidated condition of Japan's university research facilities.

### Areas of Strategic Expenditure

Selected R&D programs designated as strategic include the Research and Development Program on Basic Technologies for Future Industries, designed to develop basic technologies in the fields of new materials, biotechnology, new electronic devices and superconductivity. Another strategic R&D program is the Japan Key Technology Centre, which provides incentives to facilitate precommercial R&D in the private sector through capital investment, loans, mediation in arranging joint research, commissioned research, research information service and invitation of researchers from overseas.

Other strategic programs are the Science and Technology Promotion Adjustment Fund, which promotes basic research in areas such as social and national needs and international joint research, Exploratory Research for Advanced Technology, Human Frontier Science Program, Space Station Program (particularly the Japanese Experiment Module —JEM) and the Precursory Research for Embryonic S&T System. Also, planning is under way to build a nation-wide high-speed research-information network to link engineers and scientists in universities and laboratories.

# REPUBLIC OF KOREA

| Statistical Overview (1991) | |
|---|---|
| GERD (Won, millions) | 4 158 441 (C$6 727 million) |
| GERD/capita (Won) | 95 239 (C$154) |
| GERD/GDP (%) | 2.02 |
| GERD by source (%): | |
| Government | 19.6 |
| Industry | 69.4 |

### S&T Policies/Objectives

The Republic of Korea's estimated 4 158 billion Won (C$6.7 billion) R&D expenditure in 1991 reflects a concerted government, industry and education sector effort to strengthen Korea's S&T sector, particularly the industrial technology base.

Korea's primary S&T policy objective is to bring Korean technological capability to the level of the Group of Seven (G-7) countries in selected strategic commercial areas by early in the next century. Korean S&T policy focuses more on learning what has already been discovered rather than on forging new S&T ground. Reflecting this goal and the needs of Korean S&T, Korea has the following policy thrusts:

- *Highly Advanced Nation (HAN) project:* In a broadly based interministry, private sector and academic effort Korea has selected several strategic technologies on which it will concentrate the nation's S&T resources. The focus is developing international competitive advantage in key technology areas.
- *Training of research and technical personnel:* The rapid expansion of Korean research in the past few years has created shortages of research and technical personnel. Korean policy recognizes that this deficiency must be rectified if Korea is to continue to expand its research programs.
- *Support for private sector research:* The private sector conducts over 70 percent of Korean S&T. Through tax incentives, financial aid and other measures, the Korean government supports private sector research.
- *Nuclear self-reliance:* The government supports nuclear technology development to free Korea from dependence on imported forms of energy and create another potential export product.
- *Science awareness:* The Korean government believes it is important to make the general public aware of the importance of technology to national development.
- *International cooperation:* Recognizing that much of the technology Korea requires to reach the technology level of the G-7 nations already exists and can be learned, the Korean government encourages international S&T collaboration.

Recognizing that it cannot acquire world-leading technology in all areas, Korea has achieved a general consensus to concentrate its international technology efforts on a limited number of realizable commercial goals. Areas chosen were required to have a high probability of success, the technology to have a proven market and any technology acquisition program to be well mapped out with clearly defined and evaluated milestones. Technologies that are not targeted do not receive government support.

### Institutional Organization

The executive branch and the Economic Planning Board set S&T budgets. The Ministry of Science and Technology (MoST) sets national S&T policy, though the Ministry of Communications, Ministry of Defence, Ministry of Trade, Industry and Energy and others have their own significant sectoral S&T programs.

There are three councils whose primary mandate is to provide S&T policy advice:

- Presidential Council on Science and Technology, made up of former senior politicians and respected scientists, this body provides S&T policy advice directly to the president.
- National Science and Technology Council, made up of senior officials and researchers, this council provides S&T policy advice to all Korean government ministries that undertake S&T.

- Committee for the Development of Science and Technology, which, under the Ministry of Science and Technology, provides policy advice to the Minister of Science and Technology.

Research is conducted through three channels in Korea: government institutes, universities and the private sector. Most of the research effort is aimed directly at the marketplace. Fully 71 percent of Korean R&D is undertaken in the private sector and 61 percent of total Korean R&D goes into the commercialization of new products. In 1992, basic research represented 13 percent of Korea's R&D spending and the entire Korean university system, combined with government-funded research labs, represented only 27 percent of Korean R&D spending. As Korean industry moves increasingly to technology-based competitive advantage, this disparity in relative spending is expected to grow. While there are a large number of private sector research institutes, the top three private sector R&D spenders in 1992 accounted for 50 percent of the total R&D expenditures of the largest 344 companies in Korea.

The biggest single government S&T spender is the Ministry of Science and Technology, which accounted for 39.8 percent of Korean government S&T spending in 1991. While each spends less individually than MoST, other line ministries' S&T expenditures combined exceed those of MoST.

Korea's S&T sector is highly compartmentalized. It consists of many narrowly defined institutes answering to different ministries, underfunded and overloaded universities whose primary task is to generate future researchers and private companies in severe competition. Though individual institutes and research centres generally perform their assigned tasks well, there is little cross-fertilization between them. If the government wants research done in an area that spans the responsibilities of several existing centres, it generally must create a new centre focusing on that particular area rather than relying on a collaborative effort between existing centres.

### Areas of Strategic Expenditure

The Highly Advanced Nation (HAN) project is an effort to quickly reach the technology levels of the G-7 countries. Technology projects were chosen in areas that Korea believes can be made internationally competitive. The policy objective is that, after a period of government seed funding and support, these technologies will have achieved critical commercial mass and government funding and overseeing will no longer be required. There is some scepticism in the Korean private sector as to whether or not many HAN project goals are realistic or attainable.

Because much of the HAN project involves the learning of existing technology, international cooperation is strongly encouraged for HAN projects. Indeed, in some projects, between 5 to 20 percent international collaboration by budget is required to qualify for Korean government HAN project funding.

The HAN project has committed some 3 727 billion Won (C$6.03 billion) to 11 key technology areas. These include advanced materials, 297 724 billion Won (C$481.62 million); automotive technology, 492 225 billion Won (C$796.26 million); biotechnology, 422 273 billion Won (C$683.10 million); semiconductors, 605 685 billion Won (C$979.80 million); integrated service and digital network, 632 983 billion Won (C$1 023.96 million); manufacturing technologies, 480 282 billion Won (C$776.94 million); and nuclear power 260 188 billion Won (C$420.90 million).

While HAN appears to be a single initiative, individual ministries and institutes have responsibility for implementing their particular elements in the plan. A compromise between unified management under one ministry and the widely varying objectives of line ministries with sectoral S&T responsibilities, the HAN project is a group of projects from disparate responsibility centres and sources of funds.

# THE NETHERLANDS

| Statistical Overview (1991) | |
|---|---|
| GERD(guilders, millions) | 10 381 (C$7 856 million) |
| GERD/capita (guilders) | 689 (C$398) |
| GERD/GDP (%) | 1.91 |
| GERD by source (%): | |
| Government | 44.9 |
| Industry | 51.2 |

### S&T Policies/Objectives

The Netherlands government has identified seven strategic S&T policy priorities:

- strengthening economic infrastructure, including programs in key industrial technology areas such as new materials, microelectronics, biotechnology and agriculture
- physical infrastructure such as transportation and the continuing Dutch problem of winning land from the sea
- environment and energy, including global warming, environmental technologies and energy conservation
- human resources (emancipation, education and public health)
- international changes (political and economic changes caused by the end of the cold war)
- social cohesion (elderly, minorities and urban issues)
- investment in culture involving Dutch and Flemish languages and arts.

In June 1993, the Ministry of Economic Affairs issued a parliamentary paper titled *Competing with Technology: An Outlook for Technology Policy*. According to the 1993 Science Budget, this Parliamentary Paper will be a biennially published report, replacing the annual *Technology Policy Survey*. To improve the Netherlands' competitive position, the government decided to concentrate its efforts in three key technology policy thrusts:

- strengthened industrial R&D
- strengthened technology infrastructure and personnel resources
- technology and society (which includes the quality of life).

### Institutional Organization

In the Netherlands, the R&D budget and policies are debated annually as a single item in Parliament.

The three main institutions involved in S&T policy making are:

- Ministry of Education and Science (reorganized in 1992)
- Ministry of Economic Affairs (reorganized in 1993)
- Advisory Council for S&T Policy.

The Minister of Education and Science prepares a national science budget every year, reviewing and commenting on the planned expenditures of all departmental budgets, except that for technology issues. This is described in a separate document titled the *Technology Policy Survey*, which is the responsibility of the Minister of Economic Affairs. A third document forming the basis for the annual parliamentary debate on S&T policy was an annual report of comments on the state science in the Netherlands, which was published by the Dutch Advisory Council for Science Policy until recently, when it was dissolved and replaced by the Advisory Council for S&T Policy. This succession was designed to put more emphasis on the market aspects of advisory work. Advice is no longer to be directed to the whole Cabinet, but directly to the two ministers mentioned above.

The Science Budget and the *Technology Policy Survey* are now the main inputs for AWT comments. This commentary is to be much more market- and project-oriented than that of its predecessor, the Dutch Advisory Council for Science Policy, which was focused on in-depth studies and analysis of the research system with emphasis on long-term development.

Extensive coordination and close cooperation between the Ministry of Education and Science and the Ministry of Economic Affairs in setting of technology, industrial and science policy are considered essential to attaining the objectives set out in the 1993 Science Budget and Technology Policy Outlook.

Reports and surveys administered by various other agencies supplement the process. One such report comes from the Consultative Committee for Research Foresight, which has a mandate to the end of 1996 to conduct surveys of industry specializations and priorities. The results of these surveys along with the Ministry of Economic Affairs' technology forecasts are used to identify and stimulate priority areas and emerging technologies. These selected fields are the basis for Innovation-oriented Research Programs, which include the establishment of dedicated Research Schools in that area. Recently established Research Schools have focused on telematics, biotechnology, process engineering, catalysis and hydrodynamics.

In addition to Research Schools, the Netherlands Organisation for Applied Scientific Research and the Netherlands' five major technology institutes also play key roles as generators and suppliers of new technologies. Other organizations whose studies have provided input to the S&T policy process include the Central Planning Bureau; the Maastricht Economic Research Institute on Innovation and Technology; the Netherlands Organisation for the Promotion of Scientific Research; and a private company, McKinsey & Company, recently commissioned by the Ministry of Economic Affairs to carry out an international policy survey (*Towards A Superior Technology Infrastructure*, 1993). This survey focused on benchmarking the instruments and mechanisms employed by the French and German governments to strengthen their industrial technology infrastructures.

### Areas of Strategic Expenditure

The government has initiated two major new programs to support industrial R&D. One is a tax benefit for businesses performing R&D, with a budget of 350 million guilders (C$270 million). The other major initiative, with a budget of 250 million guilders (C$195 million) over five years, is a set of eight technology networks focused on the basic needs of the Dutch economy (soil decontamination, physical planning, agriculture and food, an electronic highway, transportation, harbours infrastructure and biotechnology).

Five major interdepartmental projects in various areas were to have been chosen at the end of 1993 by the Ministry of Economic Affairs in collaboration with other ministries. Along with the project on Technology and Society (an effort to increase the use of technology within the public domain), other areas to be developed include the care of the elderly, environmental protection and energy conservation. Other initiatives include the Technical Development Credit Plan, Business-oriented Technology Promotion Programs and support for Business-oriented Technological Research Associations.

## NEW ZEALAND

| Statistical Overview (1991) | |
|---|---|
| GERD (NZ$ millions) | 644 (C$517 million) |
| GERD/capita (NZ$) | 189 (C$152) |
| GERD/GDP (%) | 0.88 |
| GERD by source (%): | |
| Government | 65.4 |
| Industry | 32.9 |

### S&T Policies/Objectives

New Zealand has completed a process of deep reform of its S&T governance system. The reform process was initiated in 1989, and had extensive bipartisan support from the outset. Factors leading to the reforms included substantial government deficits and debt, which imposed a requirement of greatly increased cost efficiency on government operations. A second key factor was a strong need for increased applied research, more than was being performed at universities, which were receiving extensive support for performing research. The extensive support facilitated the resetting of priorities, in part because there were fewer pressures on the ministries from various constituencies to champion their own departments and universities.

In September 1992 the Ministry of Research, Science and Technology published a statement of science priorities, *Investing in Science for Our Future,* that contained recommendations by the S&T Expert Panel (STEP), appointed to advise on long-term priorities for science in New Zealand. During the process of establishing priorities, the wider S&T community was extensively consulted and given opportunities to put forward their views and submissions, particularly following STEP's preliminary discussion paper released in May 1992.

The Ministry of Research, Science and Technology believes small countries such as New Zealand must be selective, and must define their S&T priorities on the basis of socio-economic requirements, rather than on the needs of basic science research.

STEP's long-term strategy recommendations were as follows:

- to foster a sustainable, technologically advanced society that innovates and adds value, especially to their strong base of biological production
- to raise investment in science and especially encourage the private sector to increase its own investment
- to encourage a harmonious and complementary relationship between its own R&D investment and that of the private sector
- to selectively support science in areas of critical importance and where research results can most readily be commercially exploited.

### Institutional Organization

One result of the S&T reform process was that the old Department of Scientific and Industrial Research was disbanded and replaced by the Ministry of Research, Science and Technology (MORST), which has the key responsibility for S&T policy in government. Other new structures, established to strengthen and enhance accountability to the government of research agencies which receive public funds are the Foundation for Research, Science and Technology and 10 Crown Research Institutes. The foundation allocates funding on the basis of established priorities, while the Crown Research Institutes largely replace old organizations founded by individual government departments. Each of the 10 Crown Research Institutes has a core research area: pasturage, horticultural products, field crop products, forestry and wood products, industry development, environmental health and forensic science, social and economic development, land environments, atmosphere and water, and the geosphere.

The science reforms also saw the creation of the Public Good Science Fund (PGSF), administered by the Foundation for Research, Science and Technology. The PGSF was created by forming a single competitive pool made up of funds amounting to approximately NZ$260 million (C$215 million) that previously were channelled directly to institutions by the government. Under the new contestable funding system, research agencies compete to win contracts from the foundation to undertake agreed research programs, "public good" research or projects in accordance with the government's national science priorities. The foundation funds all projects on a fully costed basis.

The Crown Research Institutes are major research performers, and obtain some 60 percent of the PGSF. These institutes have been functioning for two years, and eight are showing profits, which the government allows them to keep. Some of the institutes have been successful in marketing their R&D capabilities to various Asian clients.

New Zealand also has 12 research associations, funded primarily by their industry sectors, such as the Wool Research Association and the Heavy Engineering Research Association. Total funding for these associations is about NZ$33 million (C$27 million), with NZ$13 million (C$11 million) coming from government.

#### Areas of Strategic Expenditure

There are a number of government-funded business development programs, which are collectively known as the Enterprise Assistance Package. These programs endeavour both to foster business growth and to increase employment. They include the Technology for Business Growth Program, the Expert Assistance Grant Scheme, the Business Development Investigation Grant Scheme and the Science Technician Training Scheme.

## SINGAPORE

| Statistical Overview (1992) | |
|---|---|
| GERD (Sing. $ millions) | 949.5 (C$ 727 million) |
| GERD/capita (S$) | 337 (C$ 259) |
| GERD/GDP (%) | 1.27 |
| GERD by source (%): | |
| Government | 39.1 |
| Industry | 60.8 |

#### S&T Policies/Objectives

The Government of Singapore has diversified its economy away from the entrepot activities of 30 years ago, through the attraction of foreign investment and maintenance of a free-trading regime creating expanded manufacturing and service sectors, into a highly skilled, technically sophisticated economy. To sustain this sophisticated economy, the government has identified the fostering and development of indigenous capabilities to undertake R&D activities of international standards as a key means of maintaining Singapore's industrial competitiveness.

Strengthening of its industrial technology base appears to be the Singapore government's most important S&T-related objective, with other S&T policy initiatives contributing to this goal.

#### Institutional Organization

In 1991, the Singapore Parliament established the National Science and Technology Board (NSTB) under the Ministry of Trade and Industry. The mission of the NSTB is to develop Singapore into a centre of excellence in selected fields of S&T and to enhance competitiveness in the industrial and service sectors.

Major objectives of the NSTB include:

- promoting R&D
- coordinating the establishment of research institutes and other S&T facilities
- developing highly qualified personnel
- supporting joint S&T programs with international organizations
- promoting public awareness and recognition of the importance of S&T (e.g. National Technology Month).

In 1991, the NSTB developed a National Technology Plan to promote and develop industry-driven R&D. The plan established two basic targets:

- a national expenditure on R&D should reach 2 percent of the GDP by 1995, with a minimum 50 percent private sector share of this total
- the ratio of research scientists and engineers as a proportion of the labour force should reach 40 per 10 000 by 1995.

The plan includes the following initiatives to help achieve these targets:

- a Singapore $2-billion R&D (C$1.8 billion) fund for developing key resources in technologies, personnel and skills for industry
- tax incentives for R&D
- training and immigration policies to attract more Singaporeans into R&D, supplemented with talent from abroad
- public research institutes, funded by NSTB and oriented toward industrial technology development and transfer
- programs for assistance to industry to commercialize local R&D results.

In addition to its role as the S&T policy body, the NSTB coordinates and funds a number of key national research institutes and centres. These institutes are focused on R&D

in information technology, microelectronics, electrical and electronic systems, manufacturing technology, materials and chemicals, biotechnology, environmental technology and food and agrotechnology.

The Ministry of Education has two important institutions: the National University of Singapore (NUS) and the Nanyang Technological University (NTU). At the forefront of NUS's advanced training and research programs are three specialist institutes: the Institute of Molecular and Cell Biology, the Institute of Systems Science and the Institute of Microelectronics. The NTU has established several research centres, the most important of which appear to be the GINTIC Institute of Manufacturing Technology and the SGI Centre for Graphics and Imaging Technology.

Another key S&T organization is the Singapore Institute of Standards and Industrial Research, a national standards body with a mainly technical staff of engineers and applied scientists that number about 500 people. Its staff provide industry with services such as contract R&D, design and development, technology consultancy and training, testing and failure analysis.

### Areas of Strategic Expenditure

The Government of Singapore does not attach a high priority to the advancement of basic knowledge. Its investments in S&T are linked to the needs of its business sector and must provide a comparative advantage for Singapore. The government channels S&T funds into technology cluster areas that have been identified and accepted by business as having the highest long-term industrial development potential for Singaporeans. The government will not fund research initiatives unless they have been approved by industry. Research institutes are set up in selected technology fields and education programs are adapted accordingly to produce qualified personnel, trained in the specific technology areas. The government assists by funding these institutes and offering training and study grants to companies and individuals.

## SPAIN

| Statistical Overview (1992) | |
|---|---|
| GERD (pesetas, millions) | 500 975 (C$5 401 million) |
| GERD/capita (pesetas) | 12 840 (C$138) |
| GERD/GDP (%) | 0.85 |
| GERD by source (%): | |
| Government | 48.1 (1991) |
| Industry | 45.7 (1991) |

### S&T Policies/Objectives

Spain's investment in S&T has accelerated rapidly over the past decade. The average annual cumulative growth rate of R&D expenditures in Spain from 1982 to 1992 was 18 percent — almost double the growth in R&D spending in most OECD countries over the same period. Approximately 48 percent of R&D is financed by industry, and about 46 percent is financed by government. Spain's basic S&T objective is to strengthen and modernize its S&T base, maximizing its contribution to the country's economic and social welfare.

In 1986, the government introduced the Law for the Promotion and General Coordination of Scientific and Technical Research, which established the current framework for S&T governance in Spain (the Law of Science). The Law of Science established a National Plan for Scientific Research and Technological Development, which establishes and supports R&D priorities. The plan is a multiyear document, reviewed and updated annually by the government.

Key objectives of the plan are promotion of S&T development, promotion of industrial R&D and strengthening of collaboration between pure and applied and industry research, advancement of knowledge, and contribution to social development.

### Institutional Organization

The body managing Spain's government S&T system and policy is the Interministerial Commission for Science and Technology. It is chaired by the Minister of Education and Research, and includes the ministers of Industry, Commerce and Tourism; Foreign Affairs; Defence; Economy and Finances;

Agriculture, Fisheries and Food; Public Works and Transport; Culture; Health and Consumer Affairs; and the Cabinet Office. Secretarial support to the Interministerial Commission is provided by the General Secretariat of the National R&D Plan in the Ministry of Education and Science.

Public research organizations, financed by science-based ministries, play a key role in Spain's S&T system. The largest of these is the Higher Centre for Scientific Research, which has a budget of about 32 million pesetas (C$341 million) and 5 700 employees. Other key public research organizations are the Centre for Energy, Environmental and Technological Research, with a staff of nearly 1 400 people and an annual budget of 7 740 million pesetas (C$82 million), and the National Institute for Aerospace Technology, with over 1 400 employees and a budget of about 16 billion pesetas (C$170 million). Other key public research institutions include the National Institute for Agricultural and Food Research and Technology, the Spanish Institute for Oceanography, the Technological Geomining Institute, the Research and Experimental Centre for Public Works and the Carlos III Health Institute.

Spain's universities account for approximately half of all of the country's scientists and are its most important source of research activity. Research at the university is financed by annual budget allocations of the Ministry of Education and Research as well as by direct grants for various research projects. Spain has 42 public universities and four private universities; in 1991, student enrolment in universities was nearly 1.2 million.

Approximately 1 300 businesses carry out significant R&D activities in Spain. In 1993, business enterprise expenditure on R&D was estimated at 274.8 billion pesetas (C$2.95 billion). Of these expenditures, about 20 percent are in the electrical and electronic materials and machinery sector, 14.7 percent in the chemical industry sector, 10 percent in the automotive industry and 7.4 percent in office machinery and computers. Approximately half of the industrial R&D expenditures come from businesses with over 1 000 employees. Businesses with fewer than 50 employees account for 7.6 percent of industrial R&D expenditures.

### Areas of Strategic Expenditure

The Spanish government decided that improving the productivity and competitiveness of industry was an urgent priority to permit Spain's economy to integrate into the European Union. Several initiatives were put in place to strengthen innovation and technological development, particularly in small and medium-sized firms, which are a key component of Spain's industrial infrastructure. A key initiative was the Industrial and Technological Action Plan, initiated in 1991, to promote technology development in industry, create S&T infrastructures to serve innovation needs of industry and support Spanish businesses' access to international technology transfer networks.

Another key area of S&T focus for the government is energy R&D. A national Energy Research Plan has been developed to promote R&D in efficient use of energy, coal use technologies and nuclear energy. Other special R&D plans focus on agrarian and food R&D and on health research.

## SWEDEN

| Statistical Overview (1991) | |
|---|---|
| GERD (krona, millions) | 41 352 (C$5 258 million) |
| GERD/capita (krona) | 4 789 (C$609) |
| GERD/GDP (%) | 2.86 |
| GERD by source (%): | |
| Government | 35.3 |
| Industry | 60.5 |

### S&T Policies/Objectives

A comprehensive and long-range government research bill is introduced every three years, with a view to achieving a coherent integrated research policy. In the most recent (1993–96) bill, the priorities of the Swedish government are:

- concentrated research programs in strategic areas
- closer collaboration between universities and university colleges and the business community and society in general
- development of a greater capacity for self-renewal within research at the universities and university colleges

- increased recruitment of researchers
- extension of international collaboration.

### Institutional Organization

In the triennial S&T bills, R&D proposals are presented by government ministries in their mandate areas. Almost all ministries have within their jurisdiction several authorities of agencies with planning or executive duties for R&D. Particularly important R&D ministries, in terms of size, are those of Education, Industry, Defence, Agriculture, Health and Social Affairs, and Housing and Physical Planning.

Coordinating responsibility for S&T policy is vested in a Cabinet minister (the Deputy Prime Minister) assisted by an undersecretary of state. The Swedish Government Research Advisory Board, set up to keep the government informed on research issues, has been described as a club without much power. The government is currently re-evaluating its role. An Industrial and Technical Council attached to the Ministry of Industry is a forum for the discussion of technology-related R&D questions with representatives of educational, research and industrial interest. Other advisory bodies have been set up by different ministries.

The universities hold the dominant role as performers of publicly funded R&D. In recent proposals to legislative changes passed by the Riksdog (Parliament), the government has made the universities more independent of central planning, giving them responsibility for quality and efficiency in education and research. Decisions by the government and the Riksdog on higher education research are limited to the annual budget requests submitted by higher education establishments and by the research councils.

The National Board of Universities and Colleges, a government agency subordinate to the Ministry of Education, is concerned with the coordination and planning of national higher education, research and research training. The board compiles documentation on which the Riksdog and the government base their allocation of resources for higher education and research. The board submits annual budget requests to the government based on the requests that it receives from individual higher education units and other authorities coming within its jurisdiction. The central planning of higher education, research and research training in various fields is conducted by five sectoral board planning committees.

Sweden also has a Council for Planning and Coordination of Research, which initiates and supports socially important research in collaboration with research councils and sectoral bodies.

The National Board for Industrial and Technical Development (NUTEK) is a key organization for public support of technological development. NUTEK is instrumental in creating "competence centres" at universities, and creates and supports programs to ensure better access to new technologies for small and medium-sized firms. NUTEK has recently introduced funding (on a competitive basis) for 30 engineering research centres based on university campuses. These were selected on the basis of several criteria, including attractive research qualifications for potential international partners.

### Areas of Strategic Expenditure

Priority in 1993 was given to the funding of an ambitious program for postgraduate education (intended to double the number of doctoral degrees in 10 years, currently numbering around 1 100 such degrees per year) and for promoting research in the natural sciences. These priorities are part of a concentrated effort to use R&D to strengthen the knowledge base and, by this means, help strengthen the competitiveness of Swedish industry. Specific priority areas in this effort are information technology, biotechnology and advanced materials. Two new foundations have been established for research financing in these areas as well as for strategic environmental research. Interdepartmental programs are created for R&D focused on wood manufacturing and timber, aerospace and road vehicles. Intensive focus is also given to seeking and maintaining international S&T contacts and cooperation.

Sweden has launched several initiatives designed to strengthen the technology base of small and medium-sized firms. There are several job creation activities by the Ministry of Labour for new technology areas specifically targeted to assist them.

# TAIWAN

| Statistical Overview (1991) | |
|---|---|
| GERD (T$ millions) | 81 765 (C$3 919 million) |
| GERD/capita (T$) | 3 916 (C$188) |
| GERD/GDP (%) | 1.7 |
| GERD by source (%): | |
| Government | 52.1 |
| Industry | 46.3 |

### S&T Policies/Objectives

In the past four decades, Taiwan has developed a highly sophisticated technologically advanced economy whose chief exports are microcomputer products such as mice, monitors, motherboards and integrated circuits. Several factors explain Taiwan's rapid economic development, including astute planning by the government, which in 1959, established the National Long-term Science Development Council to promote the development of S&T.

In 1967, the National Long-term Science Development Council was reorganized as the National Science Council (NSC), reporting to the Executive Yuan (the Executive Branch of the Central Government). The chairman of the NSC is a Cabinet minister reporting directly to the Premier.

In 1986, the NSC published a 10-year National S&T Development Plan to:

- raise the standards of S&T in Taiwan
- improve the standard of living
- create an independent national defence capability.

In 1991, the 10-year plan was reformulated into a 12-year National S&T Development Plan to cover the years from 1991 to 2002. The priorities of this new plan are unchanged.

### Institutional Organization

The NSC is the chief S&T policy-making body of the government. Its primary functions are the promotion of national S&T development, support of academic research, and the development of the Hsinchu Science-based Park. It is also responsible for coordinating the contributions of all relevant government departments and agencies to the 12-year S&T Plan. However, there is no government-wide management of S&T expenditures, which are the responsibility of individual government ministries.

Taiwan has over 100 major science and research organizations. Data on most of these performers are not available, as the NSC collects and publishes statistical data only for key ministries directly involved in R&D funding.

The key S&T funding ministry is the Ministry of Economic Affairs, which has a 1994 budget of approximately C$668 million. Agencies funded by the Ministry of Economic Affairs include the S&T Advisor's Office, the Industrial Development Bureau and the Energy Commission. The NSC itself has a budget of C$607 million and funds the Precision Instrument Development Centre, the Science and Technology Information Centre, the Synchrotron Radiation Research Centre, the Laboratory Animal Breeding and Research Centre, the Centre for High-Performance Computing, the Nano Device Laboratory, the National Space Program Office and the Centre for Research on Earthquake Engineering. Other key government S&T performers include the Council of Agriculture (C$127 million), the Atomic Energy Council (C$115 million) and the S&T Advisory Office of the Ministry of Education (C$44 million).

### Areas of Strategic Expenditure

Taiwan's industrial technology has evolved from a state of almost complete dependence on foreigners to a high level of sophistication, whereby the country leads the world in production and export of many microcomputer components. Increasing self-sufficiency in industrial product and process technology (at least in key industry sectors) will continue to be pursued with the following key objectives:

- development of electronic information, automation, advanced materials, biomedicine refined chemical products and related technologies to strengthen the domestic industrial technology base

- development of geological and water resources, energy resources, machines, materials and other industrial enabling technologies to strengthen the competitiveness of Taiwan's industries
- development of environmental protection, industrial safety and related technologies, which contribute to a better quality of life.

# THE UNITED KINGDOM

| Statistical Overview (1992) | |
|---|---|
| GERD (sterling, millions) | 12 619 (C$25 345 million) |
| GERD/capita (sterling) | 218 (C$438) |
| GERD/GDP (%) | 2.12 |
| GERD by source (%): | |
| Government | 35.4 |
| Industry | 51.2 |

### S&T Policies/Objectives

The newly established Office of Science and Technology is responsible for the U.K. science budget and the coordination of national and international S&T policy.

After extensive consultation with the scientific community, institutions, industry, academia and the public, the British government in May 1993 released a White Paper, *Realizing our Potential: A Strategy for Science, Engineering and Technology.* The central theme of the paper is that maintaining the excellence of science and engineering is necessary for improving the U.K.'s competitiveness and quality of life.

Key initiatives include:

- strengthening of the S&T knowledge base
- reorganization, strengthening and integration of the research councils into the government by making them responsible to the new post of director general within the Office of Science and Technology
- promotion of partnerships between the research community and industry
- establishment of a Technology Foresight Program based on a similar Japanese initiative and designed to make the research community better aware of industry and government S&T priorities.

### Institutional Organization

After the general election of 1992, for the first time since 1964, the responsibility for coordinating all S&T issues has been given to a full Cabinet minister.

The government also created the Office of Science and Technology (OST) by integrating the former S&T Secretariat of the Cabinet Office and the Science Branch of the former Department for Education and Science. The OST is headed by the Chief Scientific Adviser and is represented at Cabinet level by the Prime Minister. It is responsible for the U.K. science budget and for the coordination of national and international S&T policy. The OST also has responsibility for the research councils and the Advisory Council on S&T as well as the functions of the former Advisory Board for the Research Councils.

While the six granting councils fund research activities, funding of the higher education infrastructure remains with the renamed Department for Education and its counterparts in Scotland, Wales and Northern Ireland.

### Areas of Strategic Expenditure

One of the major initiatives in the 1993 White Paper was the Technology Foresight Program, originally designed to identify and target technology areas where Britain can best compete in the future. As a result of a series of "pre-foresight" seminars, the program has now shifted its emphasis from technology areas to market sectors, ranging from energy to health and retailing.

In the first annual review of government S&T spending, *Forward Look of Government-funded Science, Engineering and Technology* (May 1994), the identified priority areas are civil aeronautics, telecommunications, environment, materials and biotechnology.

Major shifts in planned S&T expenditures have taken place in the Departments of Trade and Industry (DTI) and Health S&T programs. The DTI will decrease funding for R&D programs by 42 percent by 1996–97 in order to facilitate a major investment of resources and effort in innovation promotion programs, focused on strengthening the technology base of small and medium-sized firms. Specific initiatives include nearly doubled support for technology transfer and promotion of best practice technologies through a network of "Business Links" offices.

The Health Department will receive an 11-percent increase by 1996–97 for its R&D programs in an effort to enable the National Health Service to become more cost-effective. Defence research is planned to be reduced 15 percent over the next five years.

Most industry investment in British R&D is concentrated in electronics, chemicals, pharmaceuticals and aerospace sectors. Together these four sectors account for 68 percent of total business-performed R&D. Internationally, the U.K.'s interests are in the EC's Fourth Framework Programme and special attention to bilateral programs with the United States, Japan and Republic of Korea.

To complement the science policy paper, the U.K. government issued a White Paper on competitiveness in May 1994 announcing a series of measures to improve the U.K.'s economy. Among the initiatives were programs to strengthen vocational training and education as well as measures to enhance R&D collaboration between universities and business.

## THE UNITED STATES OF AMERICA

| Statistical Overview (1992) | |
|---|---|
| GERD (US$ millions) | 158 452 (C$200 125 million) |
| GERD/capita (US$) | 587 (C$741) |
| GERD/GDP (%) | 2.74 |
| GERD by source (%): | |
| Government | 46.2 |
| Industry | 50.7 |

### S&T Policies/Objectives

In the United States, government R&D expenditures are identified in the national general budget as a single-line item consisting of the R&D funding requests from the individual departments and agencies.

The current Administration is shifting S&T policy emphasis from the traditional areas of space, defence and basic research, toward an effort to advance U.S. industrial competitiveness through development and commercialization of new industrial technologies. The Administration policy objectives are outlined in the document, *Technology for America's Economic Growth: A New Direction to Build Economic Strength* (February 1993). The technology policy establishes three basic goals:

- long-term economic growth that creates jobs and protects the environment
- a government that is more productive and responsive to the needs of its citizens
- world leadership in basic science, mathematics and engineering.

The economic growth goal is pursued through the following initiatives:

- enhanced incentives for industrial innovation, including a permanent R&D tax credit and credits for investment and equipment acquisition
- defence conversion, focused on developing a single national industrial and technology base, and stressing dual-use technologies
- enhanced industrial technology development programs (Advanced Technology Program, Technology Reinvestment Program, Manufacturing Extension Partnerships and Centres, National Information Infrastructure Initiative and others)
- enhanced technology transfer from federal R&D laboratories.

The goal of more responsive government is pursued by:

- improvements in information technology
- changes in procurement policy
- enhanced energy efficiency programs.

The goal of leadership in science, mathematics and engineering is pursued by the establishment of long-term funding priorities for basic research in universities.

### Institutional Organization

Policy for S&T in the U.S. is formed primarily through interaction of the administrative and legislative parts of the government. This is a highly dynamic interactive process, which is susceptible to prevailing political conditions and pressures from various interested groups and organizations. Allocation of funding takes place only after protracted negotiations between the Administration, Congress and other players.

On the Administration side, the White House Office of Science and Technology Policy (OSTP) is a central player, providing policy guidance and program coordination. Another key player is the Office of Management and Budget (OMB), which has the responsibility for putting together the annual federal budget. Key federal S&T departments are Commerce, Defence and Energy, as well as the National Aeronautics and Space Agency, the National Institute of Health and the National Science Foundation.

Congress plays a vital role in the U.S. S&T policy through its control of the funding and program authorization process, both of which require the passing of appropriate legislation. The current Congress has been particularly active in technology legislation, passing the *National Competitiveness Act*, which implements the Administration's initiatives aimed at strengthening the civilian technology base. Congress also participates in the debate on S&T policy through the reports of its research groups such as the Office of Technology Assessment and the General Accounting Office.

As part of its recasting of the S&T policy, the current Administration has made changes to the federal S&T framework. The most significant is the creation of a new National Science and Technology Council (NSTC). The Cabinet-level NSTC coordinates and integrates science, space and technology policies throughout the federal government, develops national goals for federal S&T investments and reviews federal R&D expenditures. The NSTC has taken over the responsibilities previously spread among several interagency councils, including the Federal Coordinating Council for Science, Engineering and Technology, the National Space Council and the National Critical Materials Council.

The nine committees of the NSTC, their subcommittees and mirror-committees have recently completed an analysis of current federal spending on R&D in their areas of responsibility (e.g. Information and Communication R&D, Civilian Industrial Technology, Transportation, Education and Training, and others). Their task was to set strategic priorities for their area based on the national objectives. Some of the key points that were reported include a rationale for the current allocation of federal R&D funds. The current allocation mix was perceived to be poorly linked to the current S&T policy objectives (e.g. defence expenditures were still far too high). Funding will have to be transferred from both defence-related R&D and "big science" to areas designated as strategic priorities. Government R&D funding is expected to be flat in the future (i.e. just keep pace with inflation), making a strategic allocation of funds a key issue. Reports of the NSTC committees will be used by the OSTP and OMB to develop strategic guidelines to be followed by individual agencies in the development of their budget. The results of this first review are scheduled to be used in the formulation of the fiscal year 1996 budget.

Prior to the establishment of the NSTC, only the OMB had the authority to review agency budgets. Each individual department and agency would make its own pitch to OMB, which then prepared a consolidated budget for the federal government. The President then sent the budget to Congress for its consideration. Under the new procedure, the OMB and OSTP will jointly review the reports of the NSTC committees, and a package worked out by the two offices will then be sent to the departments and agencies where it will be studied by the "deputies' group" at the departmental deputy-secretary level. Once OSTP and OMB have considered comments and potential changes offered by the deputies, they will issue the "strategic guidance" to the agencies for their inputs into the budget process.

### Areas of Strategic Expenditure

A shift in emphasis has taken place in U.S. technology policy, which stresses the importance of using S&T to improve industrial competitiveness and of a more active role for government in assisting industry to develop and commercialize technology. The emerging consensus, however, is that the new technology policy is only beginning its shift from the technology policies of the previous Administrations. In the fiscal year 1995 budget, R&D expenditures are decreased in real terms. The bulk of the R&D programs set up during the early and mid-1980s have been preserved, and the majority will be enhanced. There is a reallocation of the R&D expenditures within the budget away from military R&D toward civilian-applied R&D activities, university-based research and R&D with potential commercial applications, new technology transfer and extension initiatives, and transport technology R&D initiatives such as clean cars, intelligent highways, high-speed rail and aeronautics.

The current Administration's approach to the S&T policy includes three changes from the past. First, it has started an effort to refocus federal resources on the U.S. industrial base away from the traditional areas of departmental missions, national laboratories and universities. Second, the emphasis on building partnerships between industry and government is integral to the Administration's approach and marks a radical departure from previous policy, which limited government's role to providing industry with incentives to invest in R&D. The third major change is that the Administration is starting to target key industry sectors for direct federal support. The key government mechanism for this is the Advanced Technology Program. In a related development, the Department of Commerce is developing "industry road maps" that include much input from industry to benchmark the competitive status, state of technology and R&D strengths and the challenges facing the various industry sectors in the United States.

# S&T Priority Setting: Trends, Experiences and Lessons

*by Vince Wright**

Priority setting in scientific research is much more than a simple matter of ranking desired activities against available resources. As in the arts, scientific research demands creativity because of the uncertainty of the outcome. So the burning issue becomes determining how to manage the unpredictable. At the same time, research activities funded by the public purse are accountable to the wider society in which they are conducted, and must be managed in support of broader socio-economic objectives.

To balance these competing principles, national governments for more than three decades have been experimenting with a rich mixture of policies, structures, processes and measurement tools. At the strategic level, priority setting in the area of science and technology (S&T) in some nations has led them to create innovative institutional structures to better focus and coordinate assets. Other nations are establishing tripartite advisory bodies to heads of state, effectively elevating the profile of S&T in national systems. And recently, several Commonwealth countries have developed White Papers to help steer the S&T priority-setting process.

In addition, many governments have tried to ensure that S&T priority setting is the product of wide-ranging consultations, not only with vested interests, but also with the public at large. Once such gathering drew representatives from Australia, Germany, Israel, Japan, the Netherlands, New Zealand, Sweden and the United Kingdom as well as the European Union and the Organisation for Economic Co-operation and Development (OECD) to an informal brainstorming session held 25–27 May 1994 in Ottawa, hosted by the Government of Canada. The purpose of this international workshop was to help S&T policy advisers from various nations and organizations compare notes and benchmark their efforts.

This article summarizes the workshop discussions.

## Recent Trends

During the 1980s, most major industrialized nations managed to maintain their levels of expenditures in research and development (R&D). OECD figures show that between 1980 and 1991, government-financed gross expenditures on R&D (GERD) as a share of total public spending was more or less maintained or even increased in all Group of Seven (G-7) most developed countries except the United States and the United Kingdom.

More recently, there has been a pronounced shift in public policy emphasis from the "S" to the "T" side of the S&T spectrum. It goes without saying that S&T public policy is no longer just an instrument for promoting scientific excellence. It is now — at least in the political rhetoric — an integral part of the industrial competitiveness agendas of most governments.

Despite the growing acknowledgment of R&D as an engine of economic growth, S&T promoters in many national governments now are being challenged increasingly to defend their portfolios as public sector debts continue to spiral upward. Since they are not mandated through statutory requirements, S&T expenditures can be particularly vulnerable to so-called "budget hawks."

In this context, S&T priority setting takes on important new meaning.

Workshop participants found no magic formula for determining priorities. The priority-setting process can often get tangled

* This article was prepared for the Chief Scientist's Office of Industry Canada by Vince Wright, a science writer working in Ottawa.

up in various factors such as institutional rigidities, political considerations and international commitments.

As one delegate noted, S&T policy and planning are not always the result of rational reflection. In some cases, they might be the product of a knee-jerk reaction by political decision makers to a particular event or pressure from a powerful constituency.

In Sweden, for example, an effective lobbying campaign by the automobile and aircraft industry (led by Saab and Volvo), rather than detailed analysis of the industry's needs, prompted the government recently to establish two special cooperative industry/ university research programs for the sector. The government and industry will share programs costs, estimated at almost $12 million annually.

In Australia, the 1989 White Paper on S&T apparently resulted from scientists' demands for more research money at an outdoor demonstration a year earlier during the official inauguration of a national S&T centre.

## Coordination and Institutional Concerns

The ubiquitous and hidden nature of S&T places a strain on all national and subnational governments to devise an effective body for coordinating S&T governance. In rare instances, S&T priority setting has been concentrated in a central agency. In most cases, there is a lead organization, usually responsible for industry development or higher education, which coordinates S&T through some form of interministerial arrangement.

Some delegates at the workshop said that coordination is really a government euphemism for organizational agreement not to interfere in each other's operations. Coordination is a particularly delicate matter in cases where a government ministry is more concerned with defending its turf than with cooperation.

This form of institutional rigidity is evident in Japan, where governmental coordination was described by delegates as comparatively weak. When the Ministry of International Trade and Industry began to take an active interest in biotechnology, it upset certain bureaus within the ministries of Health and Agriculture. Over time, however, the organizations smoothed out their differences and eventually began to exchange personnel engaged in biotechnology.

Resistance to coordination is not always confined to ministries having S&T missions. As one policy adviser noted, strong tensions can build between the lead organization designated to coordinate S&T and central agencies of government responsible for finance or treasury matters.

On balance, most workshop participants indicated that their governments had either elevated the profile of S&T in the overall government decision-making system or had fortified the coordination of S&T priority setting.

Earlier in 1994, the German government announced that the Chancellor's office would create a new Council on Research, Technology and Innovation. The council, part of the current government's electoral platform, was conceived in response to pressure from German industry, which wants a more structured dialogue on S&T priority setting.

In Washington, a new National Science and Technology Council (NSTC) has been created, composed of senior officials from major federal S&T organizations, the White House and industry. One of only three councils reporting directly to the President, NSTC will spearhead the sweeping review of federal S&T spending promised by the White House in the fall of 1993.

In the U.K., responsibility for S&T coordination was transferred from the Ministry of Education and Science to the Cabinet Office of Science and Technology (OST). The transfer, implemented after the tabling of the U.K.'s S&T White Paper in May 1993, underscored a broader shift in emphasis from the education/academic milieu to the technology/economic arena. Following the release of the S&T document, the U.K. government in May 1994 issued a White Paper on Industrial Competitiveness. While the minister responsible for OST has been assigned the coordination function, this office has control of only one fifth of the roughly $12.8 billion in total R&D expenditures of the U.K. government. (The Ministry of Defence is still the largest player in the U.K. government, accounting for more than 40 percent of expenditures, although this share is declining.)

The process of adjusting government R&D allocations in the U.K. through new priority-setting mechanisms was described by workshop participants as "evolutionary rather than revolutionary." Like other large nations, the U.K. faces the challenge of eliminating deeply entrenched boundaries both within and among S&T organizations. Within the OST's Research Councils, the allocations among the six major discipline areas have remained virtually unchanged for more than 30 years.

Institutional innovation is arguably one of the major underpinnings for effective S&T priority setting. A classic illustration of this principle is found in New Zealand, where the government has taken drastic measures to overhaul the institutional S&T machinery. Notwithstanding New Zealand's gutsy determination to deal with its financial crisis, the science reforms undertaken by government in 1989 were not driven by commitment to financial rectitude. Rather, the catalyst was the government's almost total loss of confidence in the nation's S&T enterprise, evidence of which is found in the contraction of overall R&D spending by 27 percent in real terms between 1981 and 1989.

The surgery for New Zealand's ailing science system was radical. S&T components were completely severed from mission-oriented departments and reassembled in 10 Crown Research Institutes (CRIs). The institutes operate under the *Companies Act,* a measure designed to put them on a more businesslike footing. All government S&T policy and planning were centralized in a small unit in the new Ministry of Research, Science and Technology. Government S&T expenditures meanwhile were consolidated into a Public Good Science Fund managed by the Foundation for Research Science and Technology.

With the creation of the central fund, a system of contestable funding, whereby CRIs compete and collaborate with universities and private sector labs, displaced the previous regime of block funding for S&T activities. The allocation of S&T funds now is based on the purchase of science outputs rather than payment of input costs.

## A Top-down or Bottom-up Process?

Among the more stimulating issues raised at the workshop was whether S&T priority-setting should be determined top-down or bottom-up. The top-down method is undoubtedly more efficient, but does not necessarily sit well in a pluralist system. A bottom-up approach is clearly more democratic, yet could become distorted by lobby groups. New Zealand and Australia offer examples of these contrasting processes.

New Zealand's strategy for S&T reform and the subsequent development of research priorities is clearly top-down. While the process is initiated at a higher level, there seems to be some effort to avoid micromanagement. S&T priority setting in New Zealand was portrayed at the workshop as "providing a compass, but not a road map."

The process begins with a government vision statement calling for a shift from research in support of biological production to greater emphasis on downstream, valued-added activities. In 1992, a 15-member tripartite S&T Expert Panel produced a Statement of Science Priorities for the five-year period ending in 1997–98. This was followed by a series of wider consultations to develop Sectoral Research Strategies covering 24 output classes. In the process, the industry representatives realized they were ill-equipped to adequately address the research themes. As a result, the private sector has been galvanized into making more effective contributions toward future initiatives. New Zealand will re-examine the Sectoral Research Strategies at three-year intervals, each time adopting a five- or even ten-year forward view.

Australia, which seems intent on maintaining a pluralistic approach, has deliberately avoided establishing lofty national goals for S&T priority setting. Instead, it promotes S&T priority setting at the operational level, led by government research agencies (GRAs). Within Australia's largest GRA, the Commonwealth Scientific and Industrial

Research Organization (CSIRO), research priorities are determined by examining the feasibility of the undertaking on the one hand and its attractiveness to the economy on the other. While the process is directed by CSIRO's managers, it draws heavily on advice from outsiders. To ensure the process has an impact on resource allocation, CSIRO reserves 3 percent of its annual budget for redistribution to the identified priorities.

During the workshop discussions, one of the criticisms levelled against CSIRO's process was that the priorities invariably coincide with areas of established research strength within the Australian GRA, a situation characterized as "the tail wagging the dog." One delegate then asked whether research foresight studies might be useful in addressing this issue. An answer may be forthcoming: the Australian S&T Council, the government's main source of independent policy advice, apparently is exploring the possibility of undertaking foresight studies.

## Foresight

Technology foresight programs recently have been introduced in the U.K., Germany and the Netherlands. The U.K.'s foresight process was decreed in its 1993 S&T White Paper, *Realizing Our Potential: A Strategy for Science, Engineering and Technology.* In Germany, the research foresight process was sparked three years ago by a debate in the Science Council about how to improve communications within the S&T community. In the Netherlands, the Consultative Committee for Research Foresights has a mandate to the end of 1996 to conduct surveys of industry's expertise and priorities.

The U.K.'s foresight initiative, which builds on Japanese experience in this area, is led by a panel of senior scientific advisers in government and acknowledged leaders in the industry and science communities. It has been described as an attempt to break down the communications barriers among public servants, industrialists, capitalists and scientists. Although originally designed to pinpoint technology sectors in which the U.K. has established strengths, the emphasis has since shifted to market sectors.

Although Germany has yet to create a formal structure for the research foresight process, it has nevertheless produced two studies. One is based on the Japanese *Delphi* model involving an iterative process with the research and technology community. Forward views collected from various sources are then defended before the community, once all predictions are assembled. The other German foresight study, *Technologies for the 21st Century,* was prepared by various agencies under the Bundesministerium für Forschung und Technologie (BMFT). It identifies 87 critical technologies, noting the trends toward integration in previously detached areas of S&T.

A recurring observation at the workshop was the importance of the actual process surrounding research foresight and other S&T priority-setting mechanisms. In Germany, for instance, the government has yet to act formally on the recommendations of the *Technologies for the 21st Century* foresight study. However, it was noted that the process has already prompted several companies to approach the Fraunhofer Institute on Innovation Research about the possibility of conducting follow-up studies that are more targeted to their respective businesses.

Similarly, the view from the U.K. is that the real benefits of its foresight program will be the contacts and alliances forged during the process. Delegates anticipated that decisions and actions will be taken long before the government gets around to publishing the results of the foresight program.

## Evaluation Techniques

Most workshop delegates admitted that the most difficult aspect of S&T priority setting is the measurement of outputs. One policy adviser submitted that S&T priority setting was pointless unless proper evaluation tools are part of the process.

Acceptance of the measurement procedures by those being evaluated is critical. If the scientific community does not subscribe to the rules of the game, the resulting dissension may ultimately undermine the objectives of the process.

Unlike the S&T input indicators, which are comparatively easy to measure, output indicators are often more elusive. To the extent that output indicators can be gauged, they should not be examined in isolation, one delegate warned.

Output indicators can reflect the state of confidence in a national S&T system. On that basis, it was suggested that rates of change in desired directions are the most important measures for governments to track.

Two of the more interesting approaches to evaluation are found in the U.K. and Australia.

The U.K. now is publishing an annual audit of government S&T spending, known as the *Forward Look,* in an effort to gauge the progress being made on the objectives outlined in the 1993 S&T White Paper. For government departments, the *Forward Look* provides a framework for mapping out strategies over 10 to 20 years, rather than the two-year planning cycles instituted by the U.K. Treasury. The Ministry of Defence, for instance, now is able to devise longer-term plans for the development of dual-use (military/civilian) technologies.

Australia devotes considerable resources to evaluating the S&T system. The research agencies conduct their own cost/benefit analyses, while a series of government bureaus are routinely engaged in a regular process of evaluating R&D programs and particular fields of S&T.

The Bureau of Industry Economics, which is attached to the Ministry of Industry, Science and Technology, recently completed an assessment of Australia's 150-percent tax deduction for industrial R&D performers. The bureau reported that the tax breaks did induce a substantial increase in industrial R&D investment, but now appear to have lost their incentive appeal to stimulate more industrial R&D. Consequently, the government's 1994 budget has lowered the threshold for tax-qualified R&D expenditures to allow more small companies to exploit the incentives.

## The Changing Roles of Universities

Most presentations and discussions at the workshop touched on the role of universities in training highly skilled personnel and knowledge providers as a growing factor in priority setting. As governments shift toward knowledge-based technology policies, delegates made clear that universities must be more closely connected to economic decision-making processes.

One of the European representatives suggested that universities managed to remain detached from economic considerations so long as expansion of higher education was a dominant concern of governments. But now universities face increasing demands to become more active in partnerships, knowledge transfer and enterprise formation.

In the U.K., many scholars hold the view that excellence in science will find its own level. While delegates regarded this kind of thinking as falling out of favour, they noted the U.K. government remains determined to preserve its strong pool of basic science as a fundamental piece of infrastructure for longer-term socio-economic needs.

Also noted was the progressive view in the U.K. that excellence in science can and should find a utilitarian role. The U.K. government therefore recently introduced a new competitive research award for scientists who are able to attract money from industry for longer-term generic research. For example, a chemist who obtains funding from, say, a detergent company requiring a window on cutting-edge colloid chemistry research in the U.K. and elsewhere would receive matching cash from the U.K. government with virtually no strings attached, on the understanding that the scientist's work has already been judged as both good and relevant by the industry sponsor.

In Israel, there appears to be growing concern that the universities and research institutes, which have always maintained a high degree of autonomy, are drifting farther away from the country's core industries. It was noted that at least 50 percent of research in those institutions is in life sciences, an area of S&T that is immediately applicable to only a tiny fraction of Israel's current industrial base. (The lion's share of Israel's advanced technology companies, which in 1993 generated an outstanding 70 percent of the country's $10 billion in exports, excluding diamonds, are in the information technology sector.) In response, Israel has taken modest steps toward encouraging its universities to become more entrepreneurial. Direct government aid has recently been made available for R&D start-up companies and for organizations to create technology incubators. Still unresolved is the debate in Israel over the unusually high proportion of public expenditure (1.2 percent of gross domestic product) devoted to research in universities and non-government institutes.

Sweden also spends a large amount of money on higher-education research. More than 80 percent of the $2.6 billion-plus in total government R&D expenditures annually is allocated to Sweden's universities. Swedish S&T policy makers are concerned that very little of the university research is industry-relevant, as evidenced by the comparatively meagre amount of university R&D funding supplied by businesses.

To address this issue, Sweden's National Board for Industrial and Technical Development (NUTEK) in May 1994 concluded an Engineering Research Centres competition that culminated in the selection of 30 centres covering a broad spectrum of technologies. Selected from 320 applications, the new centres are designed to mobilize industrially relevant, multidisciplinary research teams over a sustained period of five to ten years. NUTEK is committing $1.5 million to $2 million annually to each centre, with the expectation that Swedish industry will provide matching support in both cash and kind.

Australia also has been actively realigning its higher-education and government R&D resources in support of industrial needs. A total of 51 organizations have been established under Australia's Cooperative Research Centres Program (CRCP), a mechanism aimed at dealing with the fragmentation of R&D activities across jurisdictional boundaries.

The Australian government provides matching dollars for a minimum of seven years. Although CRCP is still in its infancy, there is already evidence of the program's success, at least in the eyes of the Australian government. In the latest federal budget, funding was promised for an additional 10 centres.

## Basic Science and International Cooperation

Delegates noted the growing tendency among many governments to seek shorter-term gains from university research investment in the face of conflicting goals for longer-term, basic science among other sectors. One observer noted that Japan, in particular, appears to be caught between escalating support for the advancement of knowledge and government constraints in the opposite direction. Nevertheless, the Japanese government, which funds about 16 percent of the nation's total R&D effort, seems willing to deploy basic science spending flexibly to the extent that its investment can be coupled to international cooperative ventures. The Japanese-led multilateral Human Frontiers Science Program is one such example.

Germany's BMFT determined more than a decade ago that more of its basic science, particularly medium- and large-scale projects, must be carried out through bilateral and multilateral arrangements. On the multilateral front, Germany's S&T priority setting is increasingly influenced by R&D initiatives of the European Union. The 12 member states of the EU have traditionally allocated an average of 4 percent of their civilian R&D spending to precompetitive research projects in the EU's framework programs.

This percentage varies widely from country to country. In Germany, less than 2 percent of civilian R&D spending has been pumped into EU programs.

However, the workshop was told that budgetary restraint is forcing German researchers to seek out more opportunities in the EU's $17.5-billion Fourth Framework Programme for the five-year period through 1998. This trend is already visible in the field of information technology.

## Public Awareness/ Acceptance Issues

In pluralist democracies, one of the toughest challenges for those guiding the S&T priority-setting process is to capture the attention of ordinary citizens. Several delegates expressed concern that the general public tend to be scientifically illiterate and have little appreciation for knowledge as an instrument of growth in the new economy. Public apathy has meant that S&T priority setting in many nations is an exercise conducted largely by elitist self-interest groups, with the public at large generally informed after the fact.

According to one conference delegate, G-7 Finance Ministers agreed at their recent meeting in Detroit that governments are not devoting enough resources to the promotion of science culture. Another noted that science in Japan is more difficult to sell than engineering. Japanese citizens apparently place more value on roads and bridges than on scientific discoveries.

The situation in Germany is unusual. Science culture in the country is strong, with recent public opinion polls showing almost 90 percent of Germans generally in favour of the promotion of S&T as a driver of economic growth. However, a more detailed level of inquiry shows low public acceptance of certain technologies, especially genetic engineering and parts of the neurosciences. The German public's loud opposition to some of these new frontiers of science has complicated the S&T priority-setting process. Although genetic engineering and neurosciences are regarded as significant areas of potential growth, the German government finds itself trying to develop these sectors economically, while at the same time recognizing public concerns. Industry, meanwhile, has apparently become impatient with the situation: Germany's large chemical and biological companies are relocating their research activities to subsidiaries in other countries where resistance is less visible.

Elsewhere, citizens seem to relegate S&T issues behind unemployment and its attendant social ills. As one conference delegate noted, technology is "seen at least as much as a job destroyer as a job creator." This issue was clearly a priority at the G-7 Finance Ministers' meeting. Among the follow-up measures from the Detroit summit was an instruction to the OECD to undertake new studies on the linkages between technology and employment. The OECD's employment study, released in June 1994, argues that technology is not a major destroyer of jobs.

## Consensus

The workshop discussions confirmed that S&T priority setting for many advanced technological nations has become a major government preoccupation. Fiscal restraint is requiring many governments to be more selective in the allocation of their limited resources. In most cases, the issue is not whether to spend more or less, but how to spend more effectively while satisfying the demands of many competing interests.

Several delegates characterized S&T priority setting as a tricky balancing act. Governments must find a way to reconcile business's desire to exploit economic opportunities with the general public's anxieties about some of the new frontiers of science. Genetic engineering is but one example of a field where the two have clashed in controversy.

In maintaining the necessary equilibrium, governments were urged to be both reactive and proactive, particularly in ordering their own affairs. More specifically, governments must seek ways to strengthen the coordination of their S&T investments.

Coordination seemed to delegates to be effective in dealing with the institutional rigidities that can sabotage the priority-setting process. It provides a strong basis for adaptability — the reallocation of S&T assets — in a world marked by ever-increasing change.

Several delegates commented on their trials with research and technology foresight. Being a new tool for many nations, it may be too early to tell whether it will prove useful. The implication was that many priority-setting exercises do not focus enough on how S&T will unfold over the next decade. Nevertheless, one delegate suggested that the research foresight process would yield benefits, albeit intangible ones, before the results of studies are actually published. The very process was said to stimulate decision making and action, so the means might become more important than the end in itself.

If the benefits are intangible, how are they to be measured, especially in an era of government accountability? The consensus at the workshop was that S&T policy makers are already experiencing difficulty evaluating the tangible outputs. It was suggested that governments must track the rate of change in a desired direction by monitoring the full range of inputs and outputs. In the final analysis, however, those involved in S&T priority setting will have to rely both on logical measurement as well as on intuitive feel for what works and what does not.

There was widespread acceptance at the workshop that the task of S&T priority setting must be viewed as a never-ending process. Like science itself, the only constant in S&T management is change. As one delegate noted, a nation can never stand still in this field.

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