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Science and Technology Activities and Impacts:

A framework for a Statistical information System

1998

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Canada owes the success of its statistical system to a long-standing partnership between Statistics Canada, the citizens of Canada, its businesses, governments and other institutions. Accurate and timely statistical information could not be produced without their continued cooperation and goodwill.

Foreword

Change, incessant change, has been a distinguishing feature of the last two decades of this century. In fact, change has been so pervasive that it has affected, for better or for worse, the life of every Canadian. Most changes have had their origin in the rapid advancement in knowledge generation and in the speedy diffusion and application of this knowledge. The Internet, for example, is transforming the way people shop, bank, learn and entertain themselves.

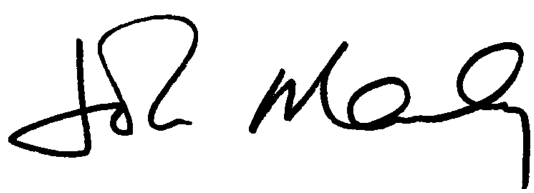
At no time has Canadian society, its environment and economy been more dependent on science and technology as it is today. To maintain a standard of living that is the envy of many, Canadians need to improve their ability to acquire, generate and apply new knowledge. The federal government is committed to assist Canadians in meeting this challenge. Towards this end, the Government has increased its funding for the Granting Councils, allocated $800 million to the Canada Foundation for Innovation and established Technology Partnerships Canada.

The federal government has also launched a winning strategy for making Canada the most connected country in the world by the year 2000. Through *Connecting Canadians* initiatives, growing numbers of Canadians, especially the young, gain access to resources to help them acquire skills and experience with information technology, computer networking, and electronic information management.

Another important part of the Government's commitment is to improve our understanding of how new knowledge, especially in science and technology, translates into economic growth and social change. In March 1996, Industry Canada funded the Information System for Science and Technology Project at Statistics Canada in response to recommendations coming out of the Federal Review of Science and Technology.

The purpose of the Project was to produce useful indicators and a framework to tie them together into a coherent picture of science and technology activities in Canada. In its first two years the Project has produced new information on innovation in service industries, on the use and planned use of biotechnologies, on the use of the Internet, on the flow of knowledge between sectors of the economy, and on federal spending on science and technology. It has also produced the framework that is the subject of this publication.

The framework described here is an operational instrument for the development of statistical information on the evolution of science and technology and its interactions with the society, the economy and the political system of which it is a part. It represents a milestone in the development of a classification for science and technology activities, their linkages and the related outcomes, and it makes explicit the description of the generation, the transmission and the use of scientific and technical knowledge. It will guide the indicators development program in the Information System for Science and Technology Project at Statistics Canada, now and into the next millennium.



The Honourable John Manley P.C., M.P.
Minister Responsible for Statistics Canada

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Executive Summary

The framework described here is intended as a basic operational instrument for systematic development of statistical information respecting the evolution of science and technology and its interactions with the society, the economy and the political system of which it is a part.

The framework focuses on three types of activity:

- Generation of S&T Knowledge;
- Transmission of S&T Knowledge; and,
- Use of S&T Knowledge.

It provides a classification into which all indicators of S&T activities, linkages, and outcomes can be placed. For each of these, key generic questions can be asked. The search for answers to these questions provides the basis for an indicator development programme.

The framework provides usable descriptions for:

- design of data acquisition;
- identifying significant data gaps;
- formulating priorities;
- challenging myths;
- stimulating analytical questions and hypotheses;
- comprehending the complexities of social benefits and detriments of S&T evolution; and,
- illuminating policy issues.

The framework as such does not intend to be a dynamic model of interactions of S&T with the society, the economy and the political system, although the systematic information which it fosters may provide the foundation for deeper understanding of causes and effects. The nature and details of the framework may be modified as the work on development of a statistical information system for S&T continues.

1. Introduction

This paper presents a framework for guiding the organizing of the data development and collection for an information system for science and technology statistics.

For the last two centuries, human civilization has known enormous economic and demographic growth; an increase in its capacity to move, carry and to communicate; a sophisticated knowledge of how to feed itself; a capacity to heal and to prolong life; as well as a power to detect, destroy and pollute. These developments share a common thread - the adoption of scientific principles and methods for the systematic pursuit of human knowledge and activities. But the attitude of society with respect to science and its applications has fluctuated from optimism in the wake of the invention and deployment of electric power, railways, telegraph, computers and modern medicine to the very nervous concern that followed the unleashing of atomic power, the recognition of environmental threats and ethical concerns over animal and plant genetic manipulation. However, these changes have not stopped the development of science. Indeed, if anything its pace has accelerated.

The scope of what were domestic social and economic policies has become global. Age-old social institutions tested in different cultures and enshrined by world religions have seen more challenges to their stability and future in the last half-century than in the millennium that preceded it. The nature of human activity has radically shifted from labour intensive towards knowledge intensive activity.

These and many other profound social changes have not been accompanied by the development of systematic and objective statistical information on the driving forces of science and technology. Science is an organized body of knowledge, and technology is the science of the practical. It is the knowledge that drives the change and accounts, in part, for the difficulty in defining and describing knowledge generation, transmission and use. Until recently, there has also been a limited demand for quantitative information by those who determine the way in which scientific activities are funded and new ideas appropriated.

Traditional information on processes of science and technology generation, transmission and use which has been made available to policy makers and to the public has been mainly data on how much was spent on which institutions, engaged in which activities, and in connection with which projects. While such information is necessary in an accounting *ex-post* sense, it is of little use as a basis for decisions on resource allocation or indeed for an understanding of the interactions between scientific innovation on the one hand and social, economic and political consequences on the other.

2. Framework Characteristics and Challenges

2.1 Structure and Statistical Challenges

Given the economic and social importance of S&T, the scarcity of statistical information on S&T characteristics is surprising. This paper presents a framework for the compilation of statistics on science and technology on a sound analytical and systematic basis, rooted in the extensive literature on evaluation and knowledge measurement.

Traditionally, S&T statistics have been indirect indicators and to a certain extent this is not likely to change in the near future. But for a substantially better interpretation of what those indicators mean, they must be systematically related to each other in accordance with a model of how knowledge is generated, transmitted and used in a modern society. This is why so much rides on the fruitfulness of the framework and why it is desirable that information concerned with S&T be presented in terms of a framework.

The framework described here consists of three parts:

- the classification of statistics needed to describe S&T activities;
- the systematic relating of the statistics to those analytical questions which have to be answered if the activity is to be understood; and,
- the selection of appropriate indicators to gauge the outcome of scientific and technological activities.

Supporting reasons for establishing a framework are the following.

- The need to track the ways in which scientific and technological knowledge once generated, is transmitted, made available, retrieved and put to use. This facilitates addressing questions about the impact of scientific and technological change on our economies and social institutions.

- To add to our knowledge of how social institutions change in response to the use of S&T and how those changes may affect the environment in which future innovation will take place.

- To gauge the consequences of the use of S&T in respect to their beneficial or detrimental impact on society (including public perception).

It is not possible to create the basis for an informed discussion of how changes in S&T affect human lives if the balance sheet of social consequences, for better and for worse, is not set out methodically and objectively. One guarantee is that such a balance sheet must be as complete as knowledge permits, so that it can be used in an impartial fashion. Another is to draw up a framework showing what the basic information should cover and how this information is interrelated.

There are other purposes served by a framework. One is its role in determining priorities for future information development. In spite of having been part of the panoply of national statistics for many years and the object of intense scrutiny by multilateral organizations set up to foster international harmonization, S&T statistics are undeveloped and are inadequate for assessment of the priorities that should guide future statistical development. A framework pinpoints gaps in our knowledge and thus allows for a more explicit and systematic determination of how those gaps should be filled.

Another role is derived from the fact that S&T activities and economic and social activities are strongly interactive. A framework for S&T statistical information must allow for the measurement of these interactions. Conversely, such measurement requires a framework that makes explicit the connections between the economy, social and political institutions and technical and scientific change.

A framework for S&T statistics in comparison with the system of economic accounts:

The system of economic (or national) accounts (SNA) is an integrated and systematic classification of all monetary transactions - real and virtual - which result in a change in the asset position of an economic agent (household, business, institution of arm of government). Such changes are normally obtained through production, exchange or change in relative prices. The objects of the asset position are all those resources (goods and services) that have a price (given by the market or imputed) and which have exclusive utilization.

A framework for S&T overlaps with the system of economic accounts at various junctures. For example, resources are consumed in the production of knowledge; knowledge is an essential factor to account for why some producers of goods and services fare better than others; knowledge is acquired by purchases from abroad and is sold in much the same fashion.

The SNA does not deal with the physical attributes of economic production and distribution – just with the monetary characteristics of transactions. And these transactions concern resources which are not shared.

The S&T Framework overlaps with the SNA in many ways, but differs significantly in various characteristics, including:

- *the object of measurement is not monetary but a notional unit of ‘knowledge’*
- *such a unit may be utilized simultaneously by many without depreciation*
- *the increase in knowledge may not necessarily be connected to monetary economic ‘value’ - positive or negative.*

The purpose of a framework for the compilation of statistical information is to organize systematically existing information as well as providing a place for information about to be compiled. In this S&T framework, S&T knowledge generation, transmission and use are fundamental units of observation.

S&T knowledge can be generated in many places. Research activities are not its exclusive creators. Additions to knowledge result from attempts to make the production process more efficient and as a by-product of its transmission and use.

Knowledge flows in response to many actions. The hiring of people, the purchase of books, attendance at conferences, corporate mergers and acquisitions, and reverse engineering are examples of knowledge transmission activities.

A statistical framework is there to classify the activities, linkages and outcomes which are part of the generation, transmission, and use of S&T knowledge and to suggest measures of impact, both socio-economic and within the S&T system itself. An S&T Framework facilitates the analysis of the joint significance of a wide range of statistical indicators, many of which are intrinsically related.

2.2 Limitations

Notwithstanding the design of a framework and the putting forth a set of related classifications, there are very significant limitations to what such tools can do.

Many activities intimately involved in the generation of knowledge are also involved in its transmission and use. The purpose of a knowledge generation activity is not necessarily known to its creator. Indeed, there are examples throughout the history of science of extremely fruitful additions to the stock of knowledge the use of which was only found long after the death of its creator. The generation of knowledge is not part of an orderly and linear process in which some preconditions are marshaled, knowledge gets generated; a suitable medium for its propagation is created and diffusion takes place followed by constructive use by the right agents. In the real world, many of these activities take place at once; there is iteration; there are errors in diffusion, and problems in use. Science is largely a self-organizing process with limited ‘strategic planning’ or unitary direction, or management.

The classifications that will be used to categorize relevant information are subject to caveats, including all areas of application of social and economic classifications. Caveats also apply to knowledge-related activities simply because there is still much experience to be accumulated from compiling and classifying the related statistics. In addition, the opportunities to establish causality in a domain as complex as the interaction of S&T with the economy and social institutions are virtually nil. Nonetheless, analytical effort is necessary to investigate associations among S&T activities and socio-economic events.

3. Need for a Framework for Collection of Statistics to Determine the Value of S&T

S&T activities in the framework include research and development, invention, innovation, and technology knowledge diffusion. The scope of these activities is greatly affected by the characteristics of the human, financial and institutional resources involved, and they are found in all sectors of the economy: government; business; education; and, households.

The S&T activities involve material objects as well as ideas. Robots, lasers and medicines are examples of material objects. Ideas reach us because they are embedded in reports, software, organizations, machines, systems and people. Resource characteristics include types of organization as well as the skill levels and occupation of individuals.

The following are examples of the many questions that are asked about the nature of science and technology and about its socio-economic effects:

- **Publicly Financed R&D**

  What is the role of publicly financed R&D in government and universities and to what extent do business people and others look to these sources for guidance? What does this say about the flow of ideas?

- **Skilled Workforce**

  What combination of levels of educational attainment matches labour market requirements? Are there a sufficient number of people with the right skills to adopt efficient production techniques? Are our schools appropriately responsive to labour market signals?

- **Public Awareness of S&T**

  To what extent does the public influence choices of new technologies? Does increased awareness of the impact of scientific innovation lead to informed choices of occupation and educational attainment?

- **Firm Innovation**

  What are the sources of ideas which firms use in order to innovate given that only a small number of them actually perform R&D? Are they bought or are they freely accessible or embodied in products that can be reverse engineered? What are the effects of firm innovation on demand for labour, overall and by profession and skill?

These questions cannot be answered with the statistical information available. There is a lack of documentation on the relationships among the operational components; and, in the absence of a framework, the S&T indicators which have been developed are piecemeal and at times misleading.

The use of the GERD ratio

One example of an extensively used, but misleading, indicator is the ratio of "Gross Expenditure on Research and Development" to GDP – known as the GERD ratio. In earlier days the GERD ratio was expected to complement the ratio of gross capital formation to GDP and both were to suggest by how much a country was willing to sacrifice current consumption for the sake of increasing its capacity to produce goods and services in the future. Empirical work suggests that the ratio indicates no such thing. On the whole, GERD ratios for industrialized countries are slow moving and their levels do not appear to be related to variations in GDP.

In the past, there was a simple policy framework for influencing science and technology activities based on the belief that support for R&D led to an enriched stock of ideas which would eventually be translated into higher productivity, economic growth, and social advancement. The indicators required to support analysis within such a framework were few, and consisted mainly of expenditures on the performance of R&D and the human resources engaged in R&D.

Now that basic questions about the effectiveness of R&D expenditures are increasingly being asked, such simple measures of R&D are no longer adequate. Public policy-makers and corporate decision-makers are concerned, not simply with understanding how much and where expenditures are made, but also with understanding how science and technology activities take place in a national and international context, and in the socio-economy generally. There is an increasing demand for accountability for all government programmes, including those devoted to science and technology. The private sector is also concerned with competition and profitability. Both sectors are concerned with optimal allocation of scarce resources for S&T. Increased attention to outcome indicators is necessary.

Public support for R&D and science and technology will increasingly rely upon the ability to demonstrate the positive social, economic and environmental effects that result from science and technology activities. This requires that credible and communicable indicators of the outcome and impact of science and technology activities be developed and that these demonstrate not only economic benefits but also social benefits such as improved health, quality of life, employment and social equity.

The processes of S&T knowledge generation, transfer and use are interactively and dynamically complex. S&T knowledge is not just the domain of the universities and governments, but also arises from business activities and, with globalization, from institutions abroad. It arises from the interactions between the growing number of actors, facilitated by increasing means of communication and transportation, augmented by increasing mobility of skilled workers.

The array of operational components relevant to an S&T information framework is large. Included are R&D, innovation processes, marketing, organization, legal and regulatory considerations, education, raw materials, capitalization and financing, labour force qualifications, tax structures, environmental factors, governments' policies, infrastructure elements of telecommunications, transport, computing, social infrastructure, technology transfer mechanisms, and transnational globalization.

4. The Framework

There is little underlying theory of how science and technology develops and interacts with other activities in different institutions. There are some procedural measures, many unsubstantiated beliefs and myths, and there are major information gaps. One purpose of the framework is to position possible measures of process and effect, and then to use it to identify gaps which are to be filled. A starting point for this is to take existing measures; to identify activities which are not yet measured, but which could be in the future; and to identify activities for which the means of measurement are not obvious at this point, such as the quality of life, or agreed upon measures of population health.

The framework developed here treats science and technology as an integral part of the socio-economy. It focuses on the S&T system, but includes measures of outcomes and impacts both within and outside the S&T system. The description of the S&T system makes explicit the connection between S&T activities, linkages and outcomes, and it includes a classification of S&T indicators to guide statistical work. Because S&T activities are an integral part of society and the economy, one of the greatest concerns is the impact of S&T on individuals and institutions, and the interactive reciprocal influence that the encompassing socio-economy has on the S&T system.

4.1 Science and Technology System

The S&T system, which forms the basis of the framework, is comprised of three types of activities:

- Generation of S&T Knowledge
- Transmission of S&T Knowledge
- Use of S&T Knowledge

The dynamics of the S&T system involves the flow from the site of the S&T knowledge generation to the site of the use, which requires a means of transmission to get from one site to the other, and capacities to transmit and to search and absorb.

- **Generation**

  The generation of science and technology involves the creation of new knowledge and information. This augmented S&T knowledge can be embedded in new products, processes and organizational practices, as well as in people who have specialized expertise gained through education and experience. S&T knowledge can also be codified in manuals, forms of publications, computer software and the design of products.

- **Transmission**

  The means of diffusion of S&T knowledge are varied, such as the hiring of an engineer who is an expert on the production process; the publication of an article on the production process that can be used in a firm with the technical capability to apply the technical information presented in the article; the process of formal education in the relevant subjects; a system of apprenticeships designed for on the job training; partnerships; conferences; informal communications among scientists; etc.

- **Use**

  For S&T knowledge to be used, it must be sought, understood and absorbed. This means that there must be a search and receptor capability on the part of the user who is capable of receiving and assimilating the S&T knowledge in the form that it is transmitted and then putting it to specific economic and social applications.

Dynamics

The dynamics of S&T involves the linkages between actors (individuals or organizations), the buying of embedded knowledge, the hiring of employees with S&T expertise, the acquisition of codified knowledge, and the diffusion of S&T information. To facilitate discussion of the dynamics, there must be a means of classifying activities, linkages and outcomes and an understanding that transmission is not instantaneous, but takes time, that outcomes may lag considerably behind the start of an activity, and that the impact of the outcome may take a very long time before it is detected.

4.2 Classification of Activity, Linkage and Outcome[1] Indicators

The statistical requirement is to develop statistical descriptors or indicators of the S&T system and its dynamics. A classification is proposed in which all indicators of S&T activities, linkages and outcomes can be placed. It categorizes S&T as three different types of activities within the S&T system: generation, transmission and use. For each of these,

[1] ‘Outcome’ is used to describe the result of an activity. For example, a new microchip is the outcome of a development project. The outcome may have been preceeded by more immediate ‘outputs’ of the project such as papers, designs or conferences. Some time later, there may be an impact of the outcome.

key generic questions can be asked. The search for the answers to these questions provides the basis for an indicator development programme.

The key generic questions are the following:

ACTIVITIES

Who? Who are the actors (individuals and organizations) involved in the activity? Are they government, industry or university organizations? Are they engineers or scientists or support staff?

What? What is the nature of the activity?

Where? Where is the activity taking place (geographical location and sector, e.g. industry, government or university)?

Why? When the activity is initiated, what are the objectives (i.e. cost reduction, improved product, scientific breakthrough, etc.)? Why is the actor doing the activity?

LINKAGES

How much? What resources have been committed to the activities, in terms of monetary expenditures, human resources, materials and fixed capital? Where do the resources come from and what are their characteristics?

How connected? What are the social organizations, the supporting infrastructures, discipline networks, critical prerequisites, critical constraints and the linkages between actors involved?

OUTCOMES

What result? When the activity is implemented, what are the outcomes (e.g. published article, patent, new product, etc.)?

Time, as a duration or a frequency, can be used to qualify any variable in the framework.

5. Using the Framework

The above questions can be put into a sentence,

‘For **an actor** [WHO] to perform **an activity** [WHAT]

in **a location** [WHERE]

in order to achieve **an objective** [WHY],

what are **the costs** [HOW MUCH],

the linkages and incentives [HOW CONNECTED]

in order to produce **an outcome** [WHAT RESULT]?’,

and applied to an artificial example,

‘ABC Limited [WHO] conducted **R&D**

in **nanoconductors** [WHAT],

at its research facilities in Kanata [WHERE]

in order **to increase its market share** of semi-conductors[WHY],

and spent 10 million dollars [HOW MUCH],

in conjunction with the Physics Laboratory of the University of CDE

but recouped half of it because of the

R&D tax rebate programme [HOW CONNECTED],

as the manufacturing process developed

was much cleaner in terms of the environment

[WHAT RESULT]?’.

This formulation suggests what statistics are required to give a summary outline of the dynamics of a research activity that has an origin, a purpose, an ascertainable cost, partners and allies, and a verifiable outcome.

The sentence can also be put in the form of a hypothesis to be tested as part of an analytical programme. The questions and the grammar that connects them provide an analytical tool. As part of the evolution of the framework, a controlled vocabulary can be built up, with definitions of each term, many of which already exist in the OECD guidelines for data collection. Of course, in many circumstances of interest, the data to flesh out the summary description may not be available - but the framework formulation will make explicit the information voids.

One of the uses of the framework and a structure for linking its elements is to juxtapose those variables that change with those that do not. Observation of change provides insight into the dynamics of a system. Variables may change with time, with geography, with industry, or with the characteristics of the actor or the linkages of the actors. For example, the propensity of firms to innovate may vary with region and industry and may also change with time. This can be seen from data used to populate the statistics and the indicators required by the framework. The analytical challenge is to discern statistical relationships with other variables in the framework, in order to contribute to the formulation of causal hypotheses.

Specific examples of the use of the framework are given in Appendix 1.

6. Outcome Measures and Impact Measures

Whereas outcomes are the discernable direct results of an S&T activity, impacts are those consequences for the social, economic, political and environmental system, and to science, that take longer to emerge and are often more difficult to detect and impute back to their origins. Still, one of the virtues of the framework is that it provides a place into which impacts, no matter how tentatively determined, might be classified leaving it to subsequent experience and investigation to establish whether indeed those were influenced by S&T outcomes.

Impacts can be divided into those that affect the socio-economic system and result from the introduction of an innovation, and those that affect the environment surrounding S&T activity and result from changes in social, economic or political organization. Both will have to be considered when dealing with the interactions of S&T with society at large.

There is a wealth of social and economic statistics which can be used to examine the impact of scientific and technical advances. These statistics include those on health, education, income, the environment, family social equity, demography, justice, national security, and mobility in addition to the statistics on economic performance. In what follows, some examples are given of impacts, along with the indicators needed to describe them.

- **Impact of Public Funding of R&D**

  Publicly funded R&D may result in knowledge that can be protected by intellectual property instruments and sold. Once the knowledge is transferred, its impact if applied by industry in the production of new or improved products or processes might be a substantial change in the industry's organization and standing at home and abroad. An example is an improved encryption system from a publicly funded R&D programme in software development. The system could be licensed to firms selling products on the Internet and resulting in a marked expansion in their sales figures. The measures of impact in this case are revenue growth for the firms availing themselves of the system and market share for the products sold.

- **Impact of Training**

  Colleges are responding to the need to identify and fix computer codes that will fail when they encounter dates of 2000 and beyond. They are introducing courses to train people in the programming languages used to write the " heritage software" and these people are finding jobs. The outcome of this activity is a trained college graduate. The immediate impact is the repair of the computer codes and, in the longer term, these people may continue to work as programmers and systems analysts. The socio-economic impact could well be a more or less permanent shift in undergraduates' preference for degrees in computing over and above, say, degrees in sociology.

- **Impact of an Innovation**

  If an outcome of innovation is a new product, such as a cellular telephone, there are both S&T and socio-economic impacts. The technology can diffuse throughout the economy and there can be financial indicators of production, physical measures of use and planned use, and measures of organizational change resulting from the use of cellular telephony. In the society, the use of cellular telephones has impact upon personal safety and upon communication patterns of individuals. The firm is able to produce an improved product as an outcome of its innovation activity. If the product is very successful, it may drive other firms in the industry out of business, creating unemployment and productivity gains resulting from use of the product in other industries may translate into reduced demand for labour. On the other hand, the diffusion of the product may result in employment growth in some industries that use it. The measures of socio-economic impact, in this case, are unemployment levels and labour demand.

7. Concluding Remarks

The framework deals with interactions between the various stages at which knowledge is generated and transmitted. Of course it recognizes that many of those changes affect the economy, social institutions and indeed political organization just as it recognizes that changes in the latter can affect the pace and nature of technical change and knowledge creation.

But while the framework provides a necessary reminder to take into account those changes it cannot provide in detail a logical place to classify them. If it did it would be a framework for all human activities for such is the pervasiveness of scientific and technical change. It is sufficient if there is awareness of those interactions and there is an established programme to study them by associating information on S&T with other information more specifically related to economic and social organization.

The framework described here is intended as a basic operational construct for systematic development of statistical information respecting the evolution of S&T and its interactions with the society, the economy and the political system of which it is a part.

The framework provides a productive description for:

- design of data acquisition;
- identifying significant data gaps;
- formulating priorities;
- challenging myths;
- stimulating analytical questions and hypotheses;
- comprehending the complexities of assessing social benefits and detriments of S&T evolution; and,
- appreciating the need for caution and criticism in establishing S&T policies.

The framework as such does not pretend to be a dynamic model of interactions of S&T with the society, the economy and the political system, though the systematic information which it will foster may provide a foundation for deeper understanding of cause and effect. The nature and details of the framework may be modified, perhaps in major ways, as the work on development of a statistical information system for S&T matures.

Appendices

Appendix 1: Applications of the Framework

To illustrate how the classification can be applied, three examples, are considered, one each for S&T knowledge generation, transmission, and use. The three examples are:

- Publicly funded R&D
- Skilled workforce
- Firm innovation

For each example, the issue is presented, followed by the sets of indicators that respond to the key questions. This is followed by a discussion of currently available information as well as information gaps. Several specific questions that can be answered using the indicators are presented.

A.1 Publicly funded R&D

In this example, we cannot get beyond measures of variation in inputs to publicly funded R&D. But suppose for argument's sake that we had a measure of outcome. The interesting questions would be framed in terms of the relation between inputs and outcomes. For example, other things being equal does the value of the outcome (however measured) vary in proportion to the cost of the research? Is there any evidence that certain sectors are systematically more successful than others? Do consortia or other types of informal alliances increase the chances of success? And so on.

Question	Indicator Category	Specific Indicators
Who?	Actors	• Performing institutions: government departments, universities, laboratories, colleges, hospitals, industries, etc. • Performing individuals: by field of study, institution, age, sex, etc.
What?	Activities	• Performance of R&D: by field and type of activity • Acquisition and maintenance of research infrastructure • Training and retaining of highly qualified personnel
Where?	Location	• Canada, province, municipality, industry
Why?	Objective	• Pursuit of competitiveness, quality of life, advancement of knowledge • Industry: cost reduction, improved product or service, improved export market • Post-secondary education: training, enhancement of educational provision, advancement of knowledge, industrial or public applications, community services • Human resource development, policy, security, industrial support, compliance with convention or agreement, support other levels of government
How much?	Resources	• Funding of R&D by sector • Performing R&D by sector • Number of people involved in R&D
How connected?	Process/ Linkages	• Amount of in-house research activities versus externally sponsored research • Amount of R&D through industry consortia, intra-sectoral organizations, inter-sectoral clusters and networks • Joint publications and patents
What result?	Outcome	• New products, improved products and services, publications, trained personnel • Compliance with international conventions, measures of environmental quality, longevity and health status of population • Employment of research trained personnel • Industrial investment in new technology and innovation

A number of the above indicators are currently available as they are collected by annual surveys of R&D. These include detailed statistics on resources, actors, type of activity, and location (Canada, provinces and industry).

The importance of adding a measure of outcome to these indicators is obvious. Other than establishing the facts as they apply to inputs, there is minimal analytical interest attributable to such a body of data.

A.2 Skilled workforce

One indicator that helps gauge activity in the transmission of S&T is the job placement of new S&T graduates, as human resources are an important vehicle for the transmission of S&T. The application of the classification elucidates the types of indicators that would need to be developed to provide a comprehensive statistical description of job placement of new S&T graduates.

Question	Indicator Category	Specific Indicators
Who?	Actors	• Number of individuals with relevant qualifications in the disciplines under observation
What?	Activities	• Job placement by position and industry
Where?	Location	• In Canada and abroad
Why?	Objective	• Gainful employment of graduates and increase in R&D capacity of firm, industry or economy
How much?	Resources	• Public financial support for universities and university programmes • Financial commitment by graduates
How connected?	Process/Linkages	• Link between university and firm where placement occurs
What result?	Outcome	• S&T capability within employer • S&T capability for industry

The financing of the university system and university programmes is well documented, as is the production of S&T graduates by discipline. The National Graduate Survey provides information on the flow of new S&T graduates to specific industries and records their industry two years and five years after graduation. The movement of S&T graduates to jobs outside of Canada is a gap.

The National Graduate Survey also provides information that is of use in developing indicators of whether the objectives of S&T graduates have been met as it determines the unemployment rate of new graduates and asks graduates to rate the extent to which their education contributed to their job.

Turning to the effect of job placement of S&T graduates, there are gaps as for example, the development of measures of the S&T capability of the employer and the effect of the job placement of the S&T graduate on employer S&T capability. Surrogate measures can probably be derived by relating the innovation record of a firm (and a number of relevant financial variables) to the inflow of graduates into its ranks. In addition to the obvious factual questions such as:

- In which disciplines are the graduates who are hired by the service sector?
- What percentage of the 1992 computer science graduates found jobs outside of Canada?

There are the questions of analytical interest related to the general question:

- How does the employment of an S&T graduate change the S&T capability of the employer?

The latter can only be answered once there is a systematic attempt at relating a firm's (or some grouping of firms such as an industry) innovation record to its performance as an employer of staff with certain abilities.

A.3 Firm innovation

One of the principal indicators of the **Use of S&T**is firm innovation. The application of the classification elucidates the types of indicators that would need to be developed to provide a comprehensive statistical description of firm innovation.

Question	Indicator Category	Specific Indicators
Who?	Actors	• Firms or parts of an enterprise
What?	Activities	• Type of innovation (product, process, and organizational)
Where?	Location	• Location of that part of the firm which is accountable for the innovation
Why?	Objective	• Increased market share • Improved financial ratios
How much?	Resources	• Cost ($) of innovation • People employed for innovation • Public financing of innovation
How connected?	Process/Linkages	• Public sources of information on innovation
What result?	Outcome	• Increased number of jobs • More environmentally friendly product • Direct effects on health, security etc.

Firm innovation surveys have been carried out by many countries, including Canada, over the past number of years. Statistical indicators for all of the above categories have been considerably refined through this effort to such an extent that those wishing to carry out an innovation survey have access to a very comprehensive set of possible statistical indicators all standardized in the OECD/EU Oslo Manual, *Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*. In very general terms, the conceptual work of developing a comprehensive set of statistical indicators has been done. Refinement of these indicators will continue as new insights are gained.

There are a number of analytical puzzles that would be easier to grasp if comprehensive indicators of innovation were further developed. Examples include:

- How strongly associated is export performance (increase in market share for a given product by a given firm or industry) and the use of innovative products or processes?
- Has the introduction of innovative processes or products been job creative or job destructive for the industries in which the innovation was introduced?
- To which extent has the introduction of innovative processes or products been promoted by government financed access to new technologies or new techniques?

Appendix 2: Members of the Working Group on the Development of a Framework for Science and Technology Statistics

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GLOSSARY OF TERMS

A

Activities
The creation, transmission or use of S&T knowledge, or a combination of these, are activities. More specific examples are: research and development, invention, innovation, technology adoption and the development of human resources related to these other activities. Activities are engaged in by actors.

Actors
Individuals or organizations, engaged in S&T activities, are the actors considered in this framework.

Advisory Committee
At Statistics Canada, an advisory committee is a group of individuals from outside of Statistics Canada, selected by the Chief Statistician of Canada, to provide advice on a particular subject. The Committee is supported by a Secretary who is a senior member of the Agency.

Analytical Question
A question which can be answered, in principle, by the manipulation of data and information. An example of an analytical question is whether there is a correlation between two observables, such as the propensity of a firm to innovate and the use of government innovation programmes by the firm (see Policy Question).

C

Capacity
Capacity is the power of containing, receiving, experiencing, or producing. It is used to describe the power of an actor to produce, transmit, or absorb S&T knowledge.

Classification
The assignment of items to a class. For example, the classification of a firm that provides wireless telecommunications services (except by satellite) to the NAICS industry class 51332.

Classification System
A classification system is the set of classes and the structure which relates them. An example is the North American Industry Classification System (NAICS).

D

Data
Numbers resulting from measurement. An example is the number of firms in NAICS industry 51332.

Diffusion
Diffusion is the change over time of the use of new ideas or technologies. For example, the use of wireless telephones is growing and the measure of the diffusions is the number of individuals who report having such telephones.

E

Evaluation
The process of comparing the objectives of a project with its outcomes and impacts to determine whether the work achieved the objectives and in a manner that was both efficient and effective in the allocation of resources.

F

Framework
A framework is a structure into which contents can be put. In the case of a Framework for a Statistical Information System, both the structure and the contents are a necessary part of communicating how statistical information is developed on the evolution of science and technology and its interactions with the society, the economy, and the political system of which it is a part.

G

Generation
Generation is used here for the production or creation of S&T knowledge. Knowledge generation is usually associated with R&D but it can occur in the course of invention, innovation, diffusion or in the development of human resources for these activities.

H

Hypothesis
A supposition made as a starting-point for further investigation from known facts.

I

Impact
An impact is a consequence of an outcome. Television has an impact on learning; cellular telephones have an impact on industrial organization. The impact may occur over a long period of time.

Indicator
A statistic, or combination of statistics, which provides information about an activity. An indicator of invention is the number of patents applied for by domestic inventors. A composite indicator of the resource allocation to research and development is the ratio of the gross domestic expenditure on R&D (GERD) to the gross domestic product.

Information
Information is data in context. For example, the NAICS provides the context to transform the data on the number of firms in NAICS industry 51332 into information about the industry which provides wireless telecommunication services (except by satellite).

Information System
An information system is a collection of information about parts of a system and about the connections between the parts.

Innovation
Innovation is the commercial use of invention. In surveys, it is identified by questions like the following. 'Did your firm offer new or improved products (goods or services) to your customers during 1994-1996?' 'Did your firm introduce new or improved processes in your firm during 1994-1996 for the supply of products (goods or services)?' 'Did your firm introduce any significant improvements in terms of organizational structure or internal business routines in 1994-1996?'

Institutions
Institutions are organizations for the promotion of scientific, educational, or other public or private objects. They are classified to the following sectors: abroad, business enterprise, education, government, and non-profit organizations.

Invention
Invention is the creation of a new product or process. It may or may not be protected by intellectual property instruments such as copyrights, patents, trademarks, trade secrets, plant breeders' rights, or the registration of industrial designs or integrated circuit designs.

K

Knowledge
Knowledge is a familiarity gained by experience. It may be written (codified knowledge) or possessed by individuals or groups (tacit knowledge). In the text, it refers only to

knowledge of science and technology and it is assumed to convey a capacity for action. For example, the knowledge that changing the level of the tax credit available to the industries in NAICS industry 51332 alters the number of firms in the industry, provides the government with a capacity to act.

L

Linkages
A linkage is a connection between the activities of actors in the system. It is a means by which S&T knowledge is transferred among actors. For example, a government department (actor) engaged in providing information on how to improve innovation (activity) and a firm (actor) engaged in innovation (activity) have a linkage if the information provided by the government department has been used by the firm.

M

Model
A simplified description of a system used to test hypotheses and to assist in calculations and predictions.

Myth
A traditional narrative usually embodying popular ideas on natural or social phenomena.

N

NAICS
The North American Industry Classification System (Statistics Canada Catalogue no. 12-501-XPE).

O

Objective
An objective is an end or a purpose.

Outcome
An outcome is the principal result of an activity. It may incorporate a number of outputs.

Output
An output is a result of an activity. A research project may produce outputs, such as a series of papers and patents, in order to move towards an outcome, which may be an invention, resulting from research that has been published and protected by patents.

P

Policy
A course or general plan of action (to be) adopted by a government, a party, or a person.

Policy Question
A policy question is designed to provide guidance for action. An example is, 'What conditions are necessary to encourage innovation?' The policy analysis undertaken to respond to this question may draw upon information from surveys of innovation, from case studies, or from expert opinion.

Product
A product is a good, a service, or a combination of the two.

R

Research and Development (R&D)
Research and experimental development comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of people, culture and society, and the use of this stock of knowledge to devise new applications.

S

Science and Technology (S&T)
Science and technology activities comprise systematic activities which are closely concerned with the generation, advancement, dissemination and application of scientific and technical knowledge in all fields of science and technology. These include such activities as R&D, scientific and technical education and training (STET) and scientific and technical services.

S&T Knowledge
S&T knowledge is that subset of knowledge that is obtained through S&T activities (see Knowledge).

System
A system is a set of connected parts. In this case, the parts are the actors and they are connected by linkages.

T

Technological Diffusion
The change over time of the use of technologies.

Transmission
'Transmission' refers to the moving of S&T knowledge from the source (see Generation) to the point of application (see Use). There are many means of transmission and some examples are: people; journals; conferences; and communications media, including the Internet.

U

Use
'Use' refers to the application of S&T knowledge. It can be manifested through the acquisition of ideas from journals or through licenses, through the use of technologies, or by means of effecting technological change, such as particular forms of industrial organization.

W

Working Group
A Working Group is created by an Advisory Committee to achieve a specific purpose. It draws its membership from the Committee and from experts brought in from outside the Committee and Statistics Canada.

FOR FURTHER READING

THE SCIENCE AND TECHNOLOGY REDESIGN PROJECT
INFORMATION SYSTEM FOR SCIENCE AND TECHNOLOGY PROJECT
Publications, Working Papers, Research Papers

CATALOGUED PUBLICATIONS

Annual Publication

88-202-XPB Industrial Research and Development 1997 Intentions (with 1996 preliminary estimates and 1995 actual expenditures)
88-204-XPB Federal Scientific Activities, 1997-98[e]

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No. 1 Scientific and Technological (S&T) Activities of Provincial Governments, 1987-88 to 1995-96
No. 2 The Effect of Country of Control on Industrial Research and Development (R&D) Performance in Canada, 1993
No. 3 The Provincial Research Organizations, 1995
No. 4 Federal Government Expenditures on Scientific Activities, 1997-98
No. 5 Industrial Research and Development, 1993 to 1997
No. 6 Software Research and Development (R&D) in Canadian Industry, 1995
No. 7 Distribution of Federal Expenditures on Science and Technology, by Province and Territories, 1995-96
No. 8 Total spending on Research and Development in Canada, 1986 to 1997[e], and Provinces, 1986 to 1995
No. 9 Estimation of Research and Development Expenditures in the Higher Education Sector, 1995-1996
No. 10 Research and Development (R&D) Personnel in Canada, 1986 to 1995
No. 11 Biotechnology Research and Development (R&D) in Canadian Industry, 1995
No. 12 Research and Development (R&D) Expenditures for Environmental Protection (EP) in Canadian Industry, 1995
No. 13 Research and Development (R&D) Expenditures of Private Non-Profit (PNP) Organizations, 1996

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ST-97-01 A Compendium of Science and Technology Statistics, February 1997
ST-97-02 Provincial Distribution of Federal Expenditures and Personnel on Science and Technology, 1994-95, February 1997
ST-97-03 Scientific and Technological Activities of Provincial Governments, 1989-90 to 1995-96, March 1997
ST-97-04 Federal Government Expenditures and Personnel on Activities in the Natural and Social Sciences, 1987-88 to 1996-97[e], March 1997
ST-97-05 Transfers of Funds for Research and Development in Canadian Industry, 1993, July 1997
ST-97-06 Estimation of Research and Development Expenditures in the Higher Education Sector, 1995-1996, August 1997

ST-97-07 Estimates of Canadian Research and Development Expenditures (GERD) - Canada, 1986 to 1997, and by Province, 1986 to 1995, August 1997
ST-97-08 Federal Government Expenditures and Personnel on Activities in the Natural and Social Sciences, 1988-89 to 1997-98[e], August 1997
ST-97-09 R&D Tax Treatment in Canada: A Provincial Comparison, October 1997
ST-97-10 Provincial Distribution of Federal Expenditures and Personnel on Science and Technology, 1987-88 to 1995-96, October 1997
ST-97-11 Commercialization of Intellectual Property in the Higher Education Sector: A Feasibility Study, October 1997
ST-97-12 Business Demographics as Indicators of Innovation Activity, October 1997
ST-97-13 Methodology for Estimation of Higher Education R&D Personnel, November 1997
ST-97-14 Estimates of Research and Development Personnel in Canada, 1979-1995, December 1997

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ST-98-01 A Compendium of Science and Technology Statistics, February 1998
ST-98-02 Exports and Related Employment in Canadian Industries, February 1998
ST-98-03 Job Creation, Job Destruction and Job Reallocation in the Canadian Economy, February 1998
ST-98-04 A Dynamic Analysis of the Flows of Canadian Science and Technology Graduates into the Labour Market, February 1998
ST-98-05 Biotechnology Use by Canadian Industry - 1996, March 1998
ST-98-06 An Overview of Statistical Indicators of Regional Innovation in Canada: A Provincial Comparison, March 1998

RESEARCH PAPERS - 1996 to 1998

No. 1 The State of Science and Technology Indicators in the OECD Countries, by Benoit Godin, August 1996
No. 2 Knowledge as a Capacity for Action, by Nico Stehr, June 1996
No. 3 Linking Outcomes for Workers to Changes in Workplace Practices: An Experimental Canadian Workplace and Employee Survey, by Garnett Picot and Ted Wannell, June 1996
No. 4 Are the Costs and Benefits of Health Research Measurable? by M.B. Wilk, February 1997
No. 5 Technology and Economic Growth: A Survey, by Petr Hanel and Jorge Niosi, April 1998