Analysis of the Economic Benefits of CANARIE

Prepared for

CANARIE

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Executive Summary

Introduction and background

In order for Canada to continue to enjoy rising standards of living, economists and policymakers agree that it must improve its record of productivity growth. Innovation is fundamental to improving productivity growth. Research and development (R&D) – both basic and applied – is the essential precursor to the development of innovative products and processes. For many decades, the Canadian government and governments in other western countries have recognized the importance of R&D.

Many governments not only subsidize R&D, but also facilitate the R&D process; they are in a position to not only offset the financial risk associated with private R&D and the costs of public R&D, but to make R&D more efficient: i.e., improve the rate of R&D output for each dollar of R&D expenditure or subsidy. An advanced research and education (R&E) network, such as CANARIE, is one such tool for improving the efficiency of R&D and thereby increasing innovation in an economy.

Canada has been fortunate to have been one of the first countries to recognize the importance of R&E networks. In 1993, Canada's federal and provincial governments established CA*Net: a high-speed network interconnecting Canadian universities and research institutions, and the first generation of CANARIE. Today, CANARIE, Canada's inter-provincial and international R&E network, connects some 1,100 academic and government institutions in Canada with each other and with many leading research centres in other countries.

Analytical framework and methodology

Enabling technologies, such as the CANARIE network, offer an array of economic benefits. Most crucially, these enabling technologies often have positive spillover effects. Furthermore, they often lead to improvements in the productivity of downstream users and throughout the economy. The following economic benefits analysis considers three types of economic benefits arising from CANARIE's R&E network and its R&D funding activities.

The **first order effects** correspond to the economic benefits associated with CANARIE's inputs. The **second order effects** capture the more profound impacts attributable to the outputs of CANARIE's activities. In particular, the second order effects include the economic value associated with CANARIE's role in facilitating Big Science and bandwidth-intensive research, improving general research productivity, and underpinning the development of innovative products and services. This category of effects also captures much of the spillover effects associated with CANARIE's operation of an R&E network and funding of related R&D activities in Canada. The **third order effects** capture what could be described as unintended positive outcomes that CANARIE's actions have also brought about.

Using data obtained from CANARIE, a literature review, and an online survey of chief information officers, vice-presidents of research, and principal investigators at Canadian universities, combined with a review of existing empirical research of the relationship between R&D outputs and economic performance, Nordicity estimated the first order and second order effects arising from CANARIE's operations over its 18-year history. The economic benefits of CANARIE's R&E network and R&D funding roles are analyzed separately; the results are then summed to arrive at an estimate of the overall economic impact of CANARIE's operations.

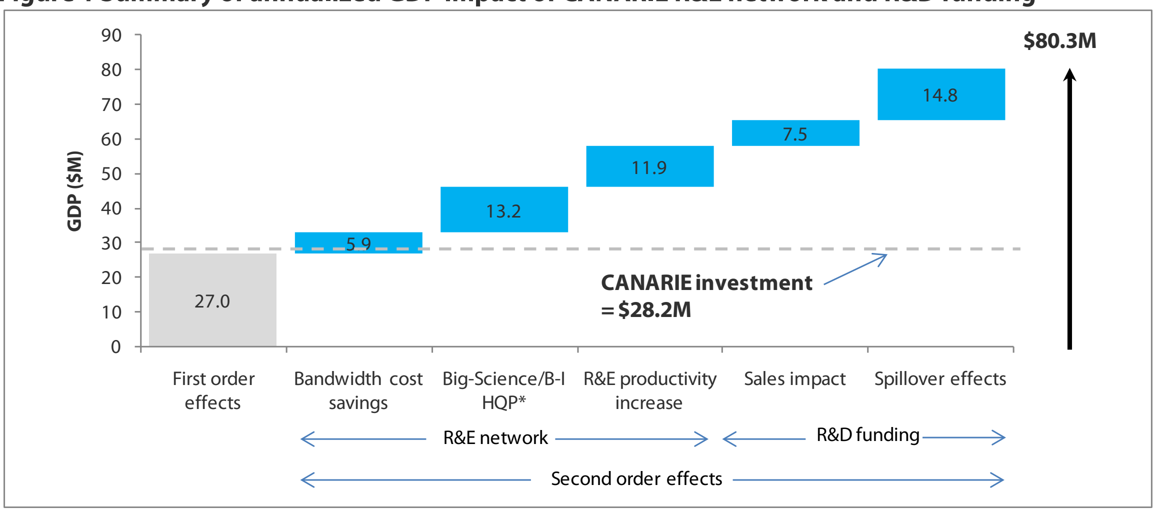
Overall economic benefits of CANARIE

In its role as an **R&E network**, CANARIE generated significant economic benefits for the Canadian economy. As an R&E network, CANARIE stimulated demand for telecommunications equipment, telecommunications services, and labour to operate and administer the network. It also helped Canadian universities reduce their expenditures on Internet bandwidth. More importantly, the CANARIE R&E network underpinned several of Canada' data-intensive Big Science projects and other bandwidth-intensive research. This research attracted, retained and trained highly qualified personnel (HQP), who, in turn, increased Canada's stock of human capital and productive capacity, and subsequently accelerated Canada's economic growth. The CANARIE R&E network also contributed to higher rates of research productivity in Canada's academic sector, which also manifested itself in higher numbers of HQP graduates from Canadian post-secondary institutions.

Over the course of its 18-year history, CANARIE also was a source of **R&D funding** within the Canadian R&E community. This funding, which totalled $179 million, leveraged an additional $194 million in funding, and led to the development and commercialization of numerous innovative products and services. These innovative products and services generated sales income (and royalty income for the Crown). More importantly, the knowledge generated by the R&D and the commercialization and adoption of the associated new products and services throughout the economy generated significant spillover effects.

When the value of the economic benefits of the CANARIE R&E network and R&D funding are added together, we find that the federal government's average annual investment of $28.2 million (in real 2010 dollars) in CANARIE generated an estimated **$80.3 million per annum** (in real 2010 dollars) in economic benefits in the form of gross domestic product (GDP) within the Canadian economy.

Figure 1 Summary of annualized GDP impact of CANARIE R&E network and R&D funding



Source: Nordicity estimates based on data from CANARIE and Statistics Canada.
*Highly qualified personnel (HQP) associated with Big Science projects and bandwidth-intensive (B-I) research.

This total GDP impact included first order effects of $27.0 million and second order effects of $53.3 million. The second order effects associated with the operation of the CANARIE R&E network totalled $31.0 million and included Internet bandwidth costs savings of $5.9 million. The incremental HQP associated with Big Science and bandwidth-intensive research contributed $13.2 million of this GDP. The incremental HQP attributable to productivity improvements at Canadian universities contributed an additional $11.9 million in GDP on an annualized basis.

The second order effects associated with CANARIE's R&D funding totalled $22.3 million in GDP, and included $7.5 million attributable to the commercialization and sales of new products and services, and $14.8 million in spillover effects.

Considering that CANARIE's operational expenditures and R&D funding averaged a combined $28.2 million per annum between 1993 and 2010 (real 2010 dollars), the economic benefits analysis indicates that **every dollar of investment in the Canadian R&E sector through CANARIE generated $2.85 in economic benefits in the form of GDP for the Canadian economy.**

1. Introduction and Background

Public R&D funding and advanced research and education networks such as CANARIE play important roles in advancing innovation and improving the competitiveness and growth of the Canadian economy

While Canada has enjoyed relatively consistent economic growth over the past decade, aside from the 2007-08 recession, the global economy is becoming increasingly competitive. In order for Canada to continue to enjoy rising standards of living, economists and policymakers agree that it must improve its record of productivity growth. At the same time, it is vital that the Canadian economy continues to transition from one based on natural resources and manufacturing to one that generates wealth from knowledge-based sectors.

Innovation is fundamental to both objectives. While Canada can improve its productivity growth through the importation of innovative products and processes, ultimately its best economic prospects come from a strategy that also develops innovative products and processes in Canada, which can be diffused around the world. Research in Motion's BlackBerry® communications service is the quintessential example of the development and diffusion of an innovative product, and demonstrates how the economic benefits from such innovation can flow back to Canada, leading to job creation – particularly for highly qualified personnel (HQP) – and higher incomes.

It is well understood that research and development (R&D) – both basic and applied – is the essential precursor to the development of innovative products and processes. For many decades, the Canadian government and governments in other western countries have recognized the importance of R&D and have implemented policies and incentives to promote it. The fact that R&D provides significant positive spillovers for economies has provided a solid policy foundation for government intervention.

Policymakers in many countries see a role for government to not only subsidize R&D activity, but also to facilitate the R&D process. There is a view that governments are in a position to not only offset the financial risk associated with private R&D and the costs of public R&D, but to make R&D more efficient: i.e., improve the rate of R&D output for each dollar of R&D expenditure or subsidy. An advanced research and education (R&E) network, such as CANARIE, represents one such tool for improving the efficiency of R&D and thereby increasing innovation and economic output.

Canada has been fortunate to have been one of the first countries to recognize the importance of R&E networks. In the early 1990s, federal and provincial governments, in cooperation with Canada's research community, developed and established one of the world's first large-scale R&E networks. In 1993, Canadian governments in partnership with collaborating universities introduced CA*Net: a high-speed network interconnecting Canadian universities and research institutions. Eighteen years later, CANARIE remains one of the world's largest R&E networks.

1.1 About CANARIE

As Canada's inter-provincial and international R&E network, CANARIE links 1,100 research institutions in Canada to each other and the leading research centres around the world

CANARIE is Canada's inter-provincial and international R&E network. Through the intra-provincial networks that it interconnects, (i.e., optical regional networks [ORANs]) CANARIE links some 1,100 institutions in Canada with each other and with many leading research centres in other countries. At a physical level, CANARIE is 19,000 km of fibre-optic cable comprised of a dedicated high-speed data communications network. It connects with 87 universities, 103 colleges, 49 CEGEPS (Collège d'enseignement général et professionnel in the province of Quebec), 84 government labs and research parks, 58 hospitals and health networks and 31 cultural institutions. Added to this list of Canadian R&E institutions are thousands of elementary and secondary schools connected via the ORANs.

1.2 Mandate and purpose of the report

This economics benefits analysis investigates and quantifies the economic impact that CANARIE – as both an R&E network and R&D funding body – had on the Canadian economy

CANARIE has now entered the final year of its current Funding Agreement with the Government of Canada (2007 to 2012). This Funding Agreement, which expires on March 31, 2012, requires CANARIE to complete and submit a summative evaluation of its programs and activities to the Minister of Industry, the federal department with primary responsibility for CANARIE.

In February 2011, CANARIE commissioned Nordicity Group Ltd. ("Nordicity") in association with Bytown Consulting Inc. ("Bytown") to complete this summative evaluation. In conjunction with the summative evaluation, CANARIE also commissioned Nordicity/Bytown to prepare an analysis of the economic benefits of CANARIE ("economic benefits analysis").

The purpose of the economics benefits analysis is to investigate and quantify the impact, in economic and monetary terms, that CANARIE – as both an R&E network and R&D funding body – has had on the Canadian economy. Unlike the summative evaluation, which focuses on the tenure of the Funding Agreement – April 1, 2007 to the present – the economic benefits analysis captures the impact of CANARIE's operations from its inception in 1993.

1.3 Outline of Report

The following report documents the results of Nordicity/Bytown's research and analysis of the economic benefits of CANARIE. Following Section 1, *Introduction and Background*, the report is divided into four additional sections.

Section 2, *Analytical Framework and Methodology,* describes the analytical approach that was used to identify and measure the economic benefits arising from CANARIE's activities. It also provides a description of the research sources and tools used to implement the analytical approach and prepare the economic benefits analysis.

The presentation of the results of economic benefits analysis is split across two sections. Section 3, *Economic Benefits of the CANARIE R&E Network*, presents Nordicity/Bytown's analysis of the economic benefits attributable to CANARIE's role as an R&E network. This analysis excludes the economic benefits from the various R&D funding programs administered by CANARIE over its 18-year history, including the Technology Development, Technology Diffusion Program (TD^2), Technology and Applications Development Program (TAD), Advanced Applications Development Program (AADP), the Phase 5 Advanced Applications Program (AAP), CANARIE Intelligent Infrastructure Program (CIIP), Network-Enabled Platforms (NEP) Program, and GreenIT Program. The economic benefits attributable to these R&D funding programs are addressed in Section 4, *Economic Benefits of CANARIE R&D Funding Programs*.

The results from both economic benefits analyses presented in this report are combined and summarized in Section 5, *Summary of Key Findings*. A list of references and data sources as well as additional description of the economic benefits analysis methodology can be found at the conclusion of the report in the *References* and appendices.

2. Analytical Framework and Methodology

In this section we provide a description of the framework that was adopted for analyzing and quantifying the economic benefits of CANARIE. The field of economic-benefits or economic-impact analysis can, at times, present a confusing array of terms: "direct" and "indirect," "spin-off" and "spillover." In this section, we try to bring some clarity and convention to the nomenclature found in this report, while at the same time, introducing the various forms or stages of economic impact and how they can be measured.

2.1 Stages of economic impacts

For enabling technologies such as an R&E network, the economic benefits go well beyond the conventional measures of direct and spin-off GDP and employment, and include spillover effects in other industries and across the economy

A typical economic impact analysis attempts to assess and quantify how some type of investment, such as a new transport facility, will affect economic activity in terms of gross domestic product (GDP), wages and employment. The original investment is often termed an *economic shock*, since it entails a significant change in the economy. The underlying rationale of such conventional economic impact analyses is often to arrive at an estimate of the ensuing incomes that a new government facility, initiative or policy will yield, and thereby, provide the basis for an economic cost-benefit analysis of any government investment in the initiative.

For this type of conventional economic analysis, an economist collects data and develops models to estimate three categories of economic impacts: *direct*, *indirect* and *induced*. The direct economic impact refers to the incremental change in economic activity in the particular industry that is subject to the economic shock. For example, in the case of the construction of a new railway line, the direct impact would capture the increased GDP and employment in the rail transportation industry (e.g., NAICS[1] 4821 *Rail Transportation)*.

The construction of a new railway line not only affects the rail transportation industry, but also creates demand for the goods and services created by other industries, most notably NAICS 3365 *Railroad Rolling Stock Manufacturing*, but many others, including the fuel wholesaling and communications industries. These impacts are referred to as *indirect* economic impacts.

The direct and indirect economic impacts both entail an increase in household incomes. Households, in turn, spend this income to purchase goods and services. This raises demand and incomes in the industries that receive these purchases. These transactions are repeated, ad infinitum, as each household in receipt of income subsequently spends some portion of this income on the purchase of goods and services. This continual re-spending of household income is referred to as the *induced* economic impact.

For many economists, the analysis of an economic shock stops at this point. The indirect and induced economic impacts can be combined to form what is called the *spin-off* economic impact. The total value of this spin-off economic impact can then be compared to the direct impact to derive an economic multiplier.

[1] North American Industry Classification System

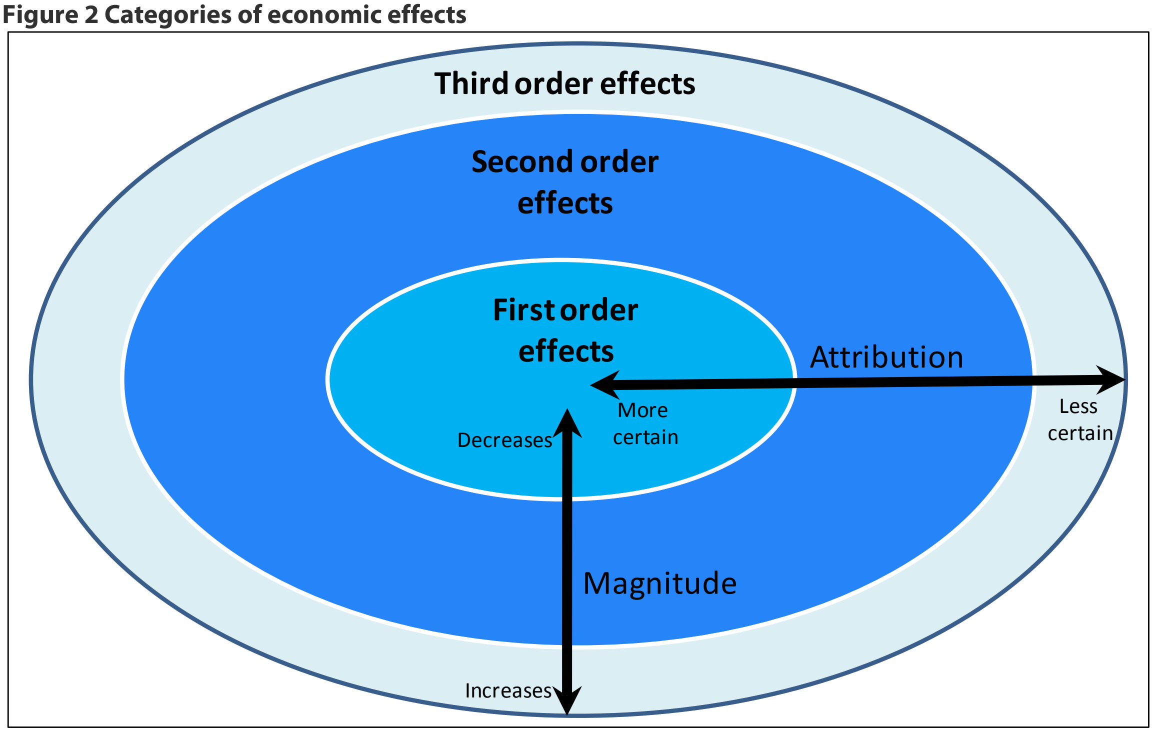
An analysis of a truly enabling technology, such as an R&E network, goes well beyond this narrow approach. For enabling technologies, the economic benefits exceed the increased demand for goods and services, and the re-spending of household income. Enabling technologies offer an added array – or additional dimension – of economic benefits. Most crucially, these enabling technologies often have positive spillover effects.

Enabling technologies often improve the productivity of downstream users, for example, through lower costs or increased diffusion of knowledge. Just as a railway can often reduce transportation costs, an R&E network can reduce its users' communications costs. When the supplier of the enabling technology captures the economic value in the pricing of its technology, this economic value is recorded in the direct impact. However, when this lower cost or higher productivity remains *unpriced* then it is considered a positive economic spillover. In other words, when the developer or originator of the productivity-enhancing technology can no longer charge a price corresponding to the value of the downstream user's productivity improvement then that downstream user is enjoying a positive economic spillover: it is no longer bearing the full opportunity cost of developing the productivity-enhancing technology.

The multiple categories of economic benefits from enabling technologies can be grouped into three stages corresponding to their relative magnitude and attribution

For the purposes of the analysis of CANARIE, we have developed a nomenclature to categorize both types of economic impacts. To further refine the stages and reach of CANARIE's economic benefits, we actually specify three types of economic benefits: **first order effects**, **second order effects** and **third order effects**. These three categories of economic benefits are depicted in Figure 2 and described further in the remainder of Section 2.

Figure 2 Categories of economic effects



The first order effects correspond to the economic benefits associated with CANARIE's *inputs*, while the second order effects correspond with the economic benefits associated with CANARIE's *outputs*. The third order effects capture what could be described as unintended positive outcomes that CANARIE's actions brought about.

In general, the magnitude or potential magnitude of each category of economic benefits increases as one moves from first to third order. In other words, third order effects offer much more leverage than first order effects: their impacts throughout an economy have the potential to be much more wide ranging. Conversely, the attribution to CANARIE – or the initiative or economic shock under analysis – of each category of economic benefit becomes less certain as one moves from the first order to the third order effects.

2.1.1 First order effects

First order effects refer to economic benefits of CANARIE's inputs and include the conventional direct, indirect and induced economic impacts that arise from the increased demand for labour, equipment and services

We use the term first order effects to refer to the economic benefits that are often associated with the increased demand that arises from an economic shock. These economic benefits include the direct, indirect and induced economic impacts that result from some type of initiative. The railroad example in Section 2.1 describes and encompasses the first order effects.

In the case of CANARIE, the first order effects include the economic benefits that arise from CANARIE's procurement of networking equipment and bandwidth, and the operation of the R&E network. It also includes the GDP and employment associated with any project funding distributed by CANARIE over the years. Finally, the procurement, wages and employment resulting from the administration of CANARIE's R&E network and funding programs would also fall within the first order effects.

Each of these aspects of CANARIE's operations generates a direct, indirect and induced economic impact. As suggested by Figure 2, the economic benefits flowing from these first order effects have a high degree of attribution to CANARIE itself, although the value of economic benefits is more limited than for the second and third order effects.

2.1.2 Second order effects

The second order effects refer to the economic impact of CANARIE's outputs and outcomes and capture the value of the R&D activity spurred by CANARIE

The economic benefits of CANARIE, of course, go well beyond the impact of its procurement and network operations. As an enabling technology, the raison d'être of CANARIE is to have a broader economic impact by spurring and facilitating R&D, and subsequently innovation, in the Canadian economy. This is a positive spillover in the sense that private actors in the economy – individuals and companies – other than the entity that originated or commercialized the new product or service also benefit.

As an R&E network, CANARIE is meant to generate economic benefits for its downstream users, primarily the researchers that utilize the network and funding programs under CANARIE's purview. In the context of CANARIE, the second order effects, therefore, are meant to measure the economic benefits associated with R&D outputs and outcomes.

By stimulating and facilitating R&D and innovation in the Canadian economy, CANARIE has a further – and potentially larger – impact on GDP and employment in the Canadian economy. The link between CANARIE, R&D, innovation, and the resulting impact on GDP and employment is less direct; moreover, the degree of attribution is more uncertain than it is for the first order effects. Estimating the second order effects necessarily requires some type of modelling. For this particular analysis, our general approach was to identify measures of R&D and innovation outputs that can be translated into economic outcomes and then attempt to attribute some portion of these economic outcomes to CANARIE.

2.1.3 Third order effects

Enabling technologies can also have significant unintended positive impacts; these comprise the category of third order effects

A category of third order effects was used to capture unintended positive impacts that have significant economic benefits. In the case of CANARIE, one such third order effect is the impact that the CANARIE R&E network has had on the availability of advanced networks and adoption of broadband Internet applications by Canadians.

Previous evaluations of CANARIE have pointed to the non-negligible impact that CANARIE has had on commercial carriers' provisioning of advanced communications networks (Hickling Corporation 1998, pp. 9-2; Hickling Arthurs Low 2006, pp. 3-9). According to our interview research, CANARIE not only put pressure on commercial carriers to expand their offerings, it also imposed price discipline on commercial carriers' advanced network offerings.

The increased supply of advanced networks to educational institutions probably exposed more Canadians to the Internet than would have otherwise occurred. In direct terms, by exposing not only researchers, but also a broad range of educators and students to the capability of an R&E network, CANARIE created a demand stimulus for applications requiring broadband communications. In indirect terms, by establishing and expanding the reach and capacity of the CANARIE R&E network, the existence of CANARIE put competitive pressure on commercial carriers to deploy advanced networks more quickly and price them more competitively. These effects constitute supply-side impacts.

The proliferation of R&E networks, therefore, also stimulated general demand for broadband services. Moreover, the increased use of broadband services would have yielded economic benefits for Canadian households and businesses by accelerating their use of productive applications – e.g., e-government applications – only available over the broadband Internet.

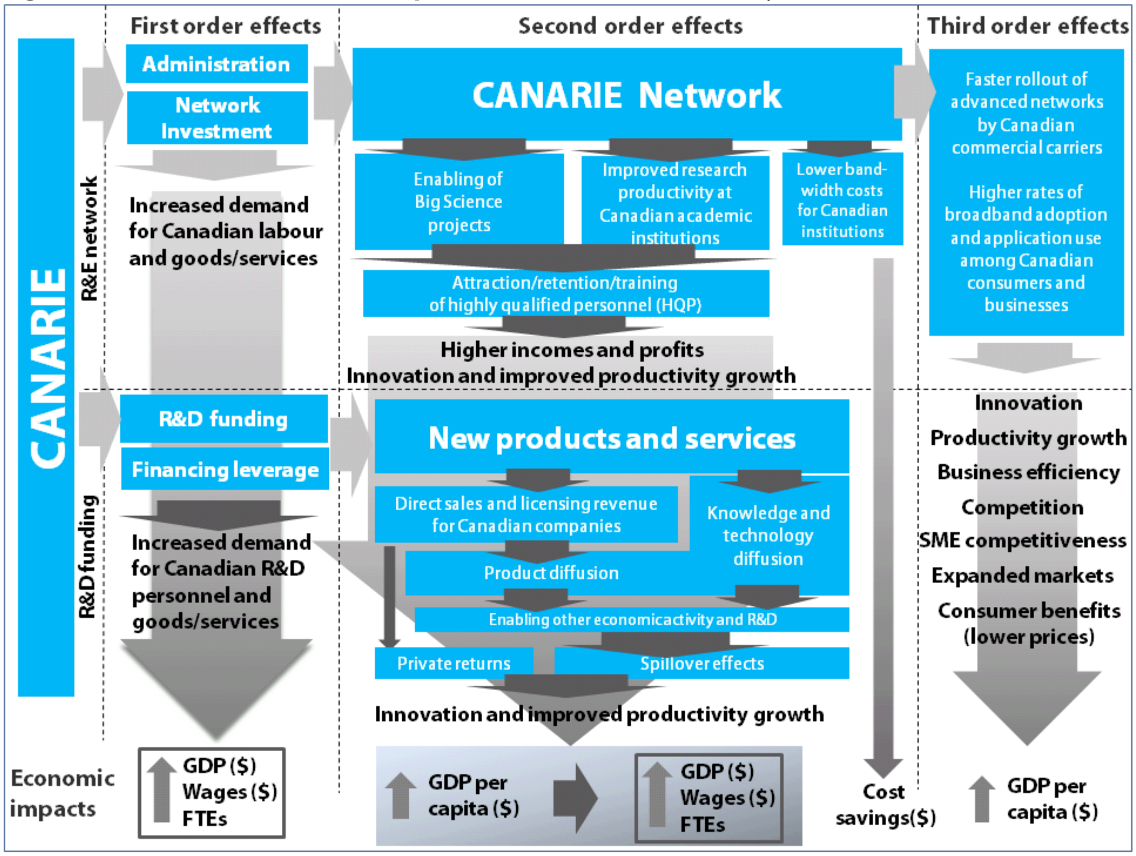
2.1.4 Overview of economic impact of CANARIE

The three stages of CANARIE's economic impact can be viewed through its two channels for R&D intervention: the operation of the R&E network and the funding of R&D

Figure 3 provides a summary overview of the channels through which CANARIE has an impact on the Canadian economy. In general, CANARIE's economic impact can be segmented in terms of the impact from its operation of an R&E network and its disbursement of R&D funding. The administration and network investments associated with the operation of the CANARIE R&E network stimulate increased demand for Canadian labour, and goods and services. CANARIE's R&D funding attracts financing leverage. Together, these financial resources stimulate demand for R&D personnel, goods and services. These combined first order effects – network administration and investment as well as R&D funding –

yield impacts on GDP, wages and employment (measured in terms of full-time equivalent workers [FTEs]).

Figure 3 Overview of CANARIE's impact on the Canadian economy



As we describe in more detail in Section 3 of this report, the second order effects of the CANARIE R&E network include the enabling of Big Science projects, improved research productivity, and lower Internet bandwidth costs for Canadian academic institutions. The primary output of enabling of the Big Science and improving research productivity is the attraction, retention and training of HQP. Higher levels of HQP in the Canadian economy increase average incomes – since higher-skilled workers generally earn higher incomes – and contribute to higher profits for Canadian businesses – because higher-skilled workers can be more productive. Above all, the presence of more HQP in the Canadian labour force increases the potential for higher rates of innovation and productivity growth within the Canadian economy.

The second order effects of CANARIE's R&D funding stem from the products and services that arise from that funding. These new products and services generate direct sales and licensing income for the companies that commercialize them. This commercialization income comprises the private returns from CANARIE-supported R&D. The diffusion of these new products and services, as well as the diffusion of the knowledge and technology arising from all R&D activities has a further enabling effect on other sectors of the economy. This enabling of other economic activity and further R&D comprises the spillover effects of CANARIE-supported R&D.

Ultimately, the outputs of CANARIE-supported R&D lead to innovation and improved productivity growth. In terms of a quantifiable economic impacts, this innovation and improved productivity growth largely manifests itself in terms of higher GDP per capita. With the higher GDP per capita, GDP, wages, and employment will increase in the Canadian economy. The Internet bandwidth cost savings from the CANARIE network can also be quantified, and translate directly into higher consumer surplus, where the consumers of Internet bandwidth services are Canadian academic institutions.

The third order effects of the CANARIE R&E network include faster rollout of advanced networks by commercial carriers and faster adoption of broadband services by Canadian consumers and businesses. Through a variety of channels, the faster proliferation of advanced networks and broadband services has a range of positive impacts on innovation, productivity growth, business efficiency, competition in markets, the competitiveness of SMEs, expanded sales markets, and significant consumer benefits in terms of lower prices for goods and services (OECD 2008, pp. 4-5). Again, these positive economic benefits ultimately manifest themselves in terms of higher GDP per capita than would have otherwise occurred.

2.2 Data sources and modelling

The methodology employed consisted of primary and secondary research, including the collection of data from CANARIE and secondary sources. An online survey was also administered to obtain additional data. Interviews provided an additional source of background information, which helped design the analytical framework and modelling. Economic modelling also played an important role in the estimation of the economic impacts.

2.2.1 Secondary research and data sources

To obtain background information and relevant data, we conducted a review of literature provided by CANARIE as well as an independent review of journal articles and reports. The literature provided by CANARIE included previous evaluations and performance audits, annual reports, and customized reports on the CANARIE organization and its role in Canada's science and technology community. CANARIE also supplied copies of reports submitted by funding recipients.

Alongside the reports provided by CANARIE, we also reviewed several academic journal articles. These articles comprised our meta-analysis. For the analysis of CANARIE, the meta-analysis focused on the research of existing empirical analyses of the relationships between R&D, innovation, commercialization of innovation, human capital formation and collaboration, and economic variables such as GDP per capita and GDP growth rates. A list of the reports and academic articles used in the preparation of this report can be found in the *References* section of this report.

Meta Analysis

Meta-analysis is a research technique whereby an analyst substitutes original empirical work with a review of existing empirical work, to develop a quantitative analysis. The quantitative relationships found in existing empirical work are then applied to issue under analysis to derive an approximation of an empirical result. For example, a meta-analysis of several research studies may find that, on average, a 25% increase in patents leads to 5% increase in per capita GDP. This empirical relationship could be applied to an academic institution's record of patent creation to establish the economic impact of its research activities.

Data from secondary sources played an important role in the preparation of the economic benefits analysis. CANARIE supplied a large array of historical data on its expenditures for network operations and funding programs; it also provided data on the royalties it has earned since its inception. We also sourced relevant data from Statistics Canada and the Association of Universities and Colleges Canada (AUCC). Statistics Canada was a source of various economic, demographic and education sector data. We sourced 2009 enrolment data as well as other education sector data from AUCC.

2.2.2 Online survey

To supplement the data from secondary sources, we worked with CANARIE to administer an online survey. The survey invitation was distributed to 46 chief information officers (CIOs) at Canadian universities, 65 vice-presidents of research (VPRs) at Canadian universities, and approximately 300 principal investigators.

The online survey was launched in early March 2011 and closed on April 1, 2011. The survey invitation was distributed by email by the Canadian University Council of CIOs (CUCCIO) and Canadian Association of University Research Administrators (CAURA). Each group of respondents answered a questionnaire customized to its respondent category.

A total of just under 100 individuals responded to the online survey. The highest response rate was in the CIO category; 59% of invited CIOs completed the survey (Table 1). These 27 CIOs' institutions accounted for 29% of total full-time enrolment in Canada in 2009. In both the VPR and principal-investigator categories, the response rate was around 20%; however, the VPR respondents' institutions accounted for only 17% of total full-time enrolment. While the response rate for the principal-investigator category was 22%, the 66 individuals that did respond also provided a data set of research characteristics.

Table 1 Online survey response rates

	Respond-ents	Popula-tion	Response rate	Enrol-ment	Total full-time enrolment	Enrolment coverage
Chief information officers	27	46	59%	263,923	899,687	29%
Vice-presidents of research	14	65	22%	149,480	899,687	17%
Principal investigators	66	~300	22%	--	--	--

Source: Nordicity calculations based on data from online survey and Association of Universities and Colleges Canada.

Given the survey response rates, we were cautious in our use of the survey data. With the exception of the CIO data, we only used the survey data to gain a better understanding of the characteristics of researchers' activities, rather than base any conclusive analysis on the data.

2.2.3 Economic modelling

The preparation of the analysis required a significant amount of economic modelling. For the first order effects, we estimated the direct, indirect and induced economic impacts. For the second order effects, we only attempted to estimate the total economic impact: i.e., the sum of direct, indirect and induced economic impacts.

The economic modelling entailed the development of approaches and calculations to estimate the output (i.e., gross output), GDP, (i.e., net output), wages, and FTEs. To estimate the latter, we also developed assumptions for average salaries in each industry under analysis and the overall economy. The estimation procedures largely relied on Statistics Canada's input-output tables. Statistics Canada's input-output tables permit an analyst to trace how increased (or decreased) expenditures in a particular industry will affect the output, GDP and employment in other industries that supply inputs to the industry under analysis. We describe the assumptions incorporated into each model as we present them throughout the report. In Appendix A, we provide additional description of the economic modelling methodology.

3. Economic Benefits of the CANARIE R&E Network

In this section we analyze the economic benefits of the CANARIE R&E network. We deliberately exclude any economic impacts that may have arisen from the R&D funding programs administered by CANARIE (which we examine in Section 4). We quantify the first-order effects arising from CANARIE's network investments and its operations. We then model the much larger second order effects arising from the R&E outputs enabled by the CANARIE R&E network. Finally, we discuss the third order effects associated with the R&E network.

3.1 First order effects

The operation of the CANARIE R&E network generates demand for labour, network equipment and services, and other goods and services, which generates n significant economic impact

The direct impact of the CANARIE network consists primarily of the economic activity arising from the network investments and operations of CANARIE. The procurement of networking equipment and access to bandwidth that form the CANARIE network generate demand for labour, goods and services in the Canadian economy. On a much smaller scale, the administration of CANARIE also generates demand for labour – i.e., CANARIE employees and subcontractors – as well as additional supplies of goods and services to maintain the administration of the network.

3.1.1 CANARIE's network invesments

CANARIE's network investments of $222 million between 1993 and 2010 generated a gross economic impact of $147 million in GDP (real 2010 dollars) and 50 FTEs

Between 1993 and 2010, CANARIE invested $221.5 million ($254.0 million in real 2010 dollars) in network equipment, other capital purchases, and payments for access to bandwidth (e.g., leases and indefeasible rights of use [IRUs]). On an annual average basis, CANARIE's network investments were equal to $14.1 million (in real 2010 dollars)

Table 2 CANARIE network investments ($ millions)

	Total expenditures 1993 to 2010 (current dollars)	Total expenditures 1993 to 2010 (real 2010 dollars)	Annual average (real 2010 dollars)
Total network investment	221.5	254.0	14.1

Source: Nordicity tabulations based on data from CANARIE and Statistics Canada.

We convert these expenditures into estimates of direct GDP using Statistics Canada's input-output tables. We also validate the information in the Statistics Canada input-output tables by examining more detailed financial statistics for the wireline telecommunications carrier industry. According to the Statistics Canada input-output tables, a one dollar increase in output in NAICS 51 *Information and Cultural Industries* results in a $0.58 increase in GDP and a $0.27 increase in labour income (i.e., wages, salaries and benefits).

Over the 18-year period, 1993 to 2010, therefore, CANARIE's network investments generated a total of $147.3 million in direct GDP in the Canadian economy (Table 3). This direct GDP included $68.6 million in wages, which, in turn, led to the creation of 50 direct FTEs[2] in the telecommunications carrier services industry.

Table 3 Direct economic impact of CANARIE network investments, 1993 to 2010 (real 2010 dollars)

	Amount
Output ($M)	254.0
GDP ($M)	147.3
Wages ($M)	68.6
Average FTE cost ($ per annum)	81,694
FTEs	50

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

3.1.2 CANARIE Inc. operations

CANARIE Inc.'s operations between 1993 and 2010 generated 27 FTEs and $2.2 million in GDP

Between 1993 and 2010, CANARIE spent $30.4 million in wages, salaries and benefits for the employees of CANARIE Inc.; it spent an additional $4.3 million on subcontractors to CANARIE Inc. CANARIE Inc. also spent $19.8 million on the purchase of goods and services over this 18-year period. In total, CANARIE Inc. spent $54.6 million in total operating expenses over the 18-year period, or an average of $3.0 million per annum.

In terms of real 2010 dollars, CANARIE Inc.'s total expenditures on in-house labour totalled $34.4 million or $1.9 million on an annualized basis; subcontractor expenses were $0.3 million on an annualized real-dollar basis; and the purchase of goods and services were equal to $1.3 million on an annualized real-dollar basis. In total CANARIE Inc.'s operating expenses over the 18-year period averaged of $3.5 million per annum on a real-dollar basis.

Table 4 CANARIE Inc. operations spending ($ millions)

	Total expenditures 1993 to 2010 (current dollars)	Total expenditures 1993 to 2010 (real 2010 dollars)	Annual average (real 2010 dollars)
CANARIE Inc. labour	30.4	34.4	1.9
Subcontractors	4.4	5.0	0.3
Purchases of goods and services	19.8	22.8	1.3
Total operating expenses	54.6	62.2	3.5

Source: Nordicity tabulations based on data from CANARIE.

We have converted CANARIE's Inc.'s expenditures to an estimate of direct economic impact by assuming that its GDP contribution was equal to its labour expenditures – for in-house employees and subcontractors. CANARIE Inc.'s operations spending ultimately led to annualized GDP of $2.2 million and the employment of 27 FTEs (Table 5). We address the economic impact of CANARIE Inc.'s procurement in the calculation of the indirect economic impact (Section 3.1.3).

[2] Throughout the report, all FTE estimates are expressed on an annualized basis.

Table 5 Direct economic impact of CANARIE Inc. (real 2010 dollars)

	CANARIE Inc. (18-year total, 1993 to 2010)	CANARIE Inc. (annualized)
Output (i.e., operating expenditures) ($M)	62.2	3.5
GDP ($M)	39.4	2.2
Wages ($M)	39.4	2.2
Average FTE cost ($ per annum)	81,694	81,694
FTEs	27	27

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

3.1.3 Spin-off and total economic impact

After taking into account the spin-off economic impacts of CANARIE's network investments and operations, the total annualized gross economic impact of CANARIE's first order effects generated $21.4 million in GDP and 200 FTEs

CANARIE's network investments and operations also generate a spin-off economic impact comprised of indirect and induced economic impacts. Using Statistics Canada's input-output tables and Nordicity's own induced economic impact multiplier (see Appendix A) we modelled the overall spin-off economic impact of the operation of the CANARIE network.

Table 6 details the spin-off and total economic impact generated by CANARIE's operations over the 18-year study period, 1993 to 2010. After estimating and adding the spin-off economic impact, CANARIE generated a total of $384.7 million in GDP in the Canadian economy, along with $212.9 million in wages and 200 FTEs (Table 6).

Table 6 Spin-off and total economic impact of CANARIE network, 1993 to 2010 (real 2010 dollars)

	Direct	Spin-off		Total
		Indirect	Induced	
GDP ($M)	186.8	101.8	96.1	384.7
Wages ($M)	108.0	53.1	51.8	212.9
Average FTE cost ($ per annum)	--	50,486	50,486	--
FTEs	80	60	60	200

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

On an annualized basis, the CANARIE R&E network generated a total economic impact equivalent to $21.4 million GDP and $11.8 million in wages; it also supported 200 FTEs (Table 7).

Table 7 Annualized total economic impact of CANARIE network, 1993 to 2010 (real 2010 dollars)

	18-year total	Annualized
GDP ($M)	384.7	21.4
Wages ($M)	212.9	11.8
FTEs	200	200

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

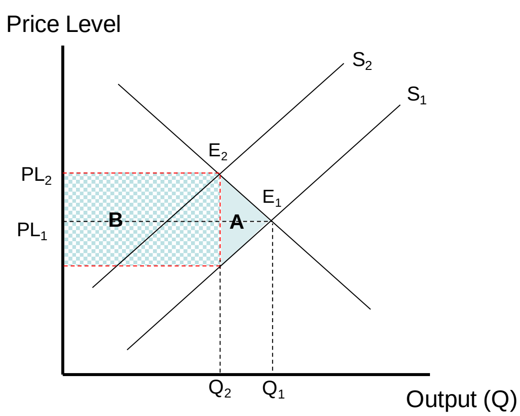
3.1.4 Net economic benefit

The net economic benefit takes into account that CANARIE's network investments and operations are financed by raising tax revenues, which have distortionary effects on the economy

Since CANARIE's network investments and operations were financed by tax revenues, one must take into account the cost that these tax revenues impose on the Canadian economy in order to arrive at an estimate of the net benefit to the Canadian economy. The collection of tax revenues not only diverts the amount of the tax revenue from private individuals and companies to government operations and programs, it also generates distortions in the economy by altering the incentives of economic agents and the allocation of resources within the economy. The sum of these distortions places additional costs on an economy and is referred to as the deadweight loss of taxation.

Deadweight loss

The imposition of a tax not only transfers income from private individuals and business to government programs and funding recipients, it can also generate a net loss to the economy. This net loss, referred to as the deadweight loss, arises when a tax alters the incentives of economic agents and leads to a reduction in output within the economy.



In the diagram (above) the shift in the supply curve (S) from S_1 to S_2 represents the effect of a tax within an economy. The price level (PL) rises from PL_1 to PL_2 and the government collects Area B (the shaded box) in the form of tax revenue. However, the tax also causes output within the economy to decrease from Q_1 to Q_2. The combination of the drop in output and increase in price level leads to a deadweight loss represented by the solid-shaded triangle A.

Baylor and Beauséjour (2004) estimated the deadweight loss of various types of taxation in Canada. For example, they found that each dollar of personal income tax reduces Canadian GDP by $0.32. Other types of taxes displayed higher rates of deadweight loss (i.e., the tax was more distortionary) or lower rates of deadweight loss. The deadweight loss rate for corporate income tax was $0.37 of GDP per incremental dollar of tax revenue; for consumption taxes the rate was $0.13 of GDP.

If we apply the deadweight loss rate of 0.32[3] to CANARIE's total government funding for operations of $308.6 million between 1993 and 2010, it implies that deadweight loss or opportunity cost of the necessary taxation of Canadians was equal to $114.0 million in GDP (Table 8).[4]

The net economic benefit of the first order effects associated with the CANARIE R&E network were equal to $15 million in annual GDP, $8.3 million in annual wages and 130 FTEs

After taking into account the deadweight loss associated with the taxation required to fund CANARIE between 1993 and 2010, we conclude that the net economic impact of the first order effects was equal to $270.7 million in GDP. This GDP included $149.9 million in wages and generated 130 FTEs. On an annualized basis, the net economic impact of CANARIE's network investments and operation generated $15.0 million in GDP, $8.3 million in wages and 130 FTEs.

Table 8 Deadweight loss of taxation and net economic impact CANARIE network and operations, 1993 to 2010 (real 2010 dollars)

	Gross economic impact (1993-2010)	Deadweight loss of taxation†	Net economic impact	Annualized net economic impact
GDP ($M)	384.7	114.0	270.7	15.0
Wages ($M)	212.9	63.1	149.9	8.3
FTEs	200	70	130	130

Source: Nordicity estimates based on data from CANARIE, Statistics Canada, and Baylor and Beauséjour (2004).
† Represents the efficiency loss (opportunity cost) to the Canadian economy of raising $303.3 million in federal tax income to fund CANARIE's network investments and operations between 1993 and 2010.

3.2 Second order effects

The second order effects of the CANARIE R&E network include the bandwidth cost savings it yields for post-secondary institutions and the more profound impacts it has on Canada's ability to generate R&D through Big Science, bandwidth-intensive research and higher research productivity

In this section, we examine the economic impact associated with three key second order effects generated by the CANARIE R&E network. First, we examine the Internet bandwidth cost savings that CANARIE generates for post-secondary institutions in Canada. We then examine the more profound impact that CANARIE has on Canada's ability to generate R&D through Big Science and bandwidth-intensive research, and higher research productivity.

[3] We use the deadweight loss rate for personal income tax since this type of tax represents the vast majority of federal government revenue.

[4] CANARIE's government funding of $308.6 million is equal to $356.2 million in real 2010 dollars. The latter amount is multiplied by 0.32 to arrive at the deadlight loss estimate of $114.0 million.

3.2.1 Introduction

An R&E network such as CANARIE can influence productivity and economic growth by promoting innovation particularly trough the development of human capital

An R&E network such as CANARIE can influence productivity and economic growth by promoting innovation and the development of human capital. We researched both of these channels through which an R&E network can ultimately affect the economy.

Innovation output

Innovation encompasses the continuous development of new products and processes that ultimately improve the manner in which an economy uses its resources and capital. Measuring innovation is a subject of much discussion and debate. Economists often attempt to measure innovation – at least on a relative basis – by collecting and comparing data on the number of academic-journal articles, patents or new products produced.

CANARIE's R&E network is inextricably linked to the production of all three of these innovation indicators. That being said, the empirical relationship between these variables and economic outcomes – namely changes in per-capita GDP or per-worker GDP, or total factor productivity[5] – is not always well established. Research by Lin and Lee (2010) was unable to establish an empirical relationship between academic-publications-per-capita and GDP-per-capita. The relationship between new products and economic growth seems self-evident; however, we found little empirical investigation of the relationship.

The body of empirical research for patents as a measure of innovation has been more active. Rao, Ahmad, Horsman and Kaptein-Russell (2001, pp. 12-14) found a positive relationship between United States (US) patents-per-capita and real-GDP-per-employed-person and an even stronger relationship between US patents-in-force and real-GDP-per-capita. The authors noted that labour productivity (GDP per worker) increases by 1.6% when the number of US patents-per-capita increases by 10% (Rao, et al. 2001, p. 13).

For the analysis of CANARIE's economic benefits, the implication is that if one can determine the number of patents caused by CANARIE then one can further model CANARIE's effect on the overall economy. Relating patent creation in causal manner to CANARIE is an empirical challenge, however; moreover, it presents issues of double counting. As such, we did not attempt to trace CANARIE's effect on patent creation and subsequent relationship with Canada's economic performance

Human capital formation

The second category of output, human capital formation, provides the most concrete basis for tracing the impact of the CANARIE R&E network's impact on the overall economy. Holbrook, Wixted, Chee, Klingbeil and Shaw-Sherlock (2008); and Martin (1998) argued that the main output of universities and university R&D is human capital (Holbrook et al. 2008, pp. 4-5; Martin 1998, p. 687). One method for measuring human capital is to first measure the number of HQP produced from this R&D and then to put a monetary estimate to the value of these HQP (Holbrook et al. 2008, pp. 4-5; Martin 1998, p. 687).

Bassanini and Scarpetta (2001) investigated the relationship between average years of schooling in the workforce and per-worker-GDP. They found that every one year increase in the average years of

[5] Total factor productivity refers to the improvement in productivity in an economy that cannot be attributed to improvements in productivity of labour, capital, land or other production inputs. It is often viewed as the improvement in productivity that can be attributed to advances in knowledge and technology.

schooling in a particular country's workforce increased its real-GDP-per-worker by 6% (Bassanini and Scarpetta 2001, p. 403). More accurately, they found that their modelling results were consistent with other empirical work that found a 6% lift in real-GDP-per-worker for every one year increase in the average years of education in the workforce (Bassanini and Scarpetta 2001, p. 403).

Bassanini and Scarpetta's (2001) empirical research has important implications for the analysis of the economic benefits arising from the outputs of an R&E network. The key role of the CANARIE R&E network is to facilitate the R&D process. One of the most reliable ways to measure the output of R&D is to measure the number of HQP generated by this R&D. Indeed, the number of HQP generated by CANARIE is one of its key performance indicators. In other words, by estimating the number of HQP associated with the CANARIE R&E network, one can estimate the monetary value of its economic impact.

Using the Bassanini and Scarpetta (2001) model also obviates the need to determine the number of patents attributable to research on the CANARIE R&E network or generated by CANARIE-supported R&D, since the human-capital effect already captures this innovation-output effect; attempting to measure both would result in double counting.

Before we estimate the human-capital impact, we briefly examine the Internet bandwidth costs savings derived by post-secondary institutions in Canada from their use of CANARIE.

3.2.2 Internet bandwidth cost savings

Canadian universities and colleges saved over $100 million in bandwidth charges between 1993 and 2010 as a result of their connectivity to CANARIE

From the online-survey data and other reports, we estimated the financial savings that post-secondary institutions realized as a result of their CANARIE connectivity. We obtained data from 21 institutions accounting for full-time enrolment of 263,923, or 29% of total full-time enrolment in Canada in 2009 of 899,867 (Association of Universities and Colleges Canada 2011). From the online survey, these institutions reported that their annual Internet bandwidth costs totalled $2.3 million in 2010. The data set suggests that total Internet bandwidth costs across Canada for post-secondary institutions were approximately $7.8 million in 2010.

On a weighted-average basis, therefore, the 21 institutions spent $8.64 per full-time student on bandwidth in 2010. At these post-secondary institutions, the portion of traffic over the CANARIE/ORAN network ranged from 1% to 99%. The weighted average was 38%.

If we assume that CANARIE did not exist and Canadian post-secondary institutions had to replace this Internet bandwidth at commercial rates, then we can assume that their commercial Internet bandwidth costs would increase by approximately 60% (38% ÷62%). On a national basis, therefore, Canadian universities' commercial Internet bandwidth costs would have increased from $7.8 million to $12.6 million – an increase of $4.8 million (Table 9). In other words, Canadian universities saved an estimated $4.8 million in 2010 in commercial Internet bandwidth costs, or $5.37 per student.

We can also use the modelled cost savings of $5.37 per student to estimate the cost savings for colleges. Full-time enrolment at Canadian colleges was 457,854 in 2008/09. As such, Canadian colleges saved an estimated $2.5 million in Internet bandwidth costs from their CANARIE connections.

Table 9 Calculation of Internet bandwidth cost savings at Canadian universities

	Survey respondents	Estimate for all universities
Number of full-time university students	263, 923	899,687
Estimated annual Internet bandwidth costs with CANARIE ($M)	2.3	7.8
CANARIE/ORAN share of Internet traffic	38%	--
Estimated annual Internet bandwidth costs without CANARIE ($M)	3.7	12.6
Internet bandwidth cost savings due to CANARIE ($M)	1.4	3.7
Internet bandwidth cost savings per student ($)	5.37	5.37

Source: Nordicity estimates based on data from survey, AUCC and Statistics Canada.

In total, therefore, connection to CANARIE saved Canadian post-secondary institutions an estimated $7.3 million in Internet bandwidth costs in 2010 or $5.37 per student. Over the 18-year period, this annual savings amounted to an estimated $106.6 million (based on annual enrolment levels) or $5.9 million on an annual basis (Table 10).

Table 10 Calculation of Internet bandwidth cost savings, 1993 to 2010

	Annual	18-year total
Number of full-time university and college students (M)	1.3	19.8
Bandwidth cost savings per student ($)	5.37	5.37
Bandwidth cost savings due to CANARIE ($M)	5.9	106.6

Source: Nordicity estimates based on data from survey, AUCC and Statistics Canada.

3.2.3 Attraction, retention and training of highly qualified personnel

The CANARIE R&E network makes an important contribution to Canadian research institutions' capacity to attract, retain and training scientists, engineers and other highly qualified personnel

While CANARIE does help post-secondary institutions reduce their Internet bandwidth costs, its more profound impact comes from its role in helping Canadian academic institutions attract, retain and train HQP. The attraction, retention and training of HQP, such as principal investigators, not only raises average incomes within the Canadian economy, but also increases the productive potential of the economy. Principal investigators also play a key role in attracting and training other HQP, facilitating more efficient R&D. Principal investigators' projects involve post-doctoral researchers and graduate students, both of whom raise the average level of education within the economy. This higher level of education – i.e., increased stock of human capital – subsequently contributes to higher incomes and productive capacity for Canadian businesses.

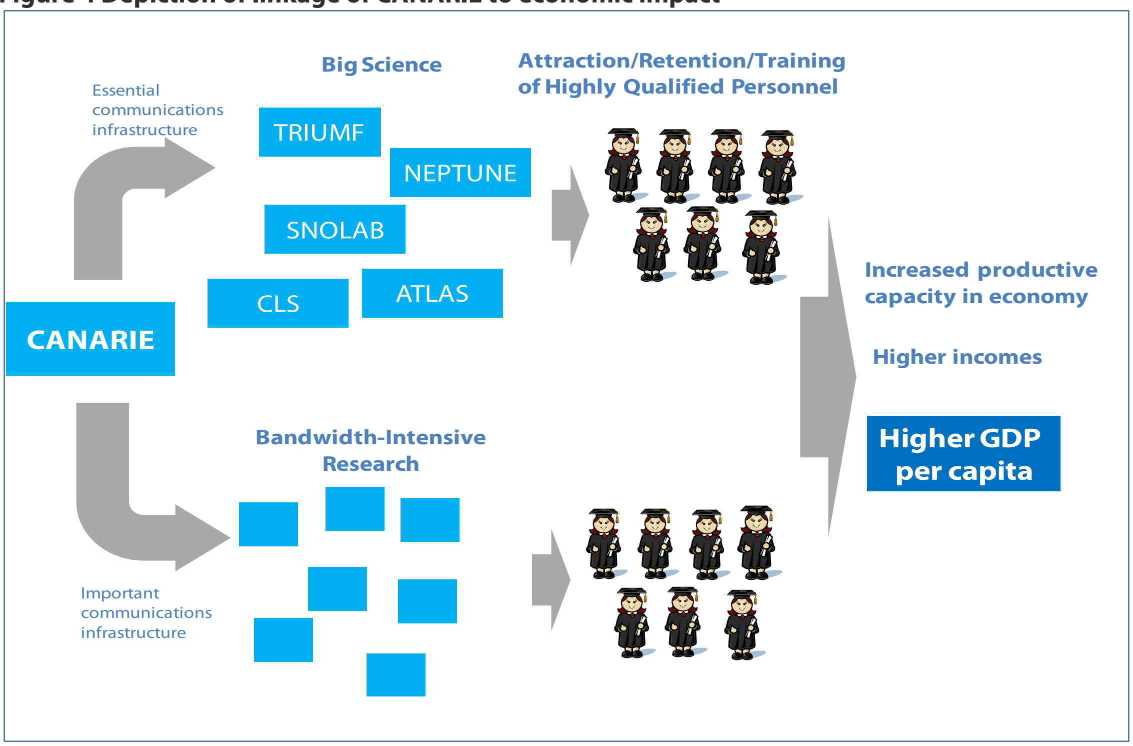
Of course, CANARIE is only one element of the Canadian research community that attracts and retains HQP. Sufficient and consistent funding, quality of life and other attributes are attractive to HQP. That being said, CANARIE does play a more prominent role in certain research areas. CANARIE is relatively more important to researchers involved in research with high bandwidth requirements – i.e., bandwidth-intensive research. These high bandwidth requirements may stem from the need to access or transfer large data files or it may arise from the need for high-performance computing (HPC) that involves numerous simultaneous computations. In particular, previous research and the research for this project pointed to the fact that CANARIE plays a critical role in supporting many of Canada's *Big Science* projects.

The CANARIE R&E network plays a critical role in supporting high-bandwidth research and high-performance computing at Canada's Big Science projects, including TRIUMF, NEPTUNE, ATLAS, SNOLAB and Canadian Light Source, which are vital to Canada's science and technology strategy

Several Canadian universities host national and internationally coordinated Big Science projects. Among these Big Science projects are TRIUMF, NEPTUNE, ATLAS, SNOLAB and Canadian Light Source. These Big Science projects are cornerstones of Canada's science and technology strategy, and serve to attract and retain HQP who would otherwise migrate to other countries to engage in the research and experiment opportunities afforded by these projects.

All of the Big Science projects have very intensive data communications requirements. CANARIE plays a critical role in fulfilling these data communications requirements, which often require dedicated point-to-point national and international connectivity. Because of CANARIE's critical role to Big Science, it arguably plays an even greater role in attracting the HQP engaged in research at the Big Science projects.

Figure 4 Depiction of linkage of CANARIE to economic impact



To estimate CANARIE's impact on the Canadian economy through Big Science and other bandwidth-intensive research, we first collected data on the HQP involved in these two types of research. Clayman, Holbrook and Wixted (2009) provided an estimate of the number of principal investigators, post-doctoral research assistants and graduate students engaged in bandwidth-intensive research. Based on a survey of 65 principal investigators at Canadian universities, they found that 53 principal investigators were involved in bandwidth-intensive research. From this survey result, Clayman et al. (2009) concluded that approximately 523 principal investigators in Canada were engaged in high-bandwidth research in

2009 (Clayman et al., 2009, p. 32). The authors further concluded that each principal investigator, in turn, attracted an average of two post-doctoral research associates and trained an average of 2.5 graduate students (Clayman et al., 2009, p. 32). We used these data along with our own collection of HQP data specific to Canada's Big Science projects to estimate the economic value of attracted and retained HQP attributable to CANARIE.

Big Science HQP

Over 800 HQP are engaged in research at Canada's five major Big Science projects – TRIUMF, NEPTUNE, SNOLAB, ATLAS and Canadian Light Source

From public reports and documents submitted to CANARIE, we tabulated – and in some cases estimated – the number of HQP engaged in research at five of Canada's major Big Science projects – TRIUMF, NEPTUNE, SNOLAB, ATLAS and Canadian Light Source. The tabulation exercise focussed on obtaining a solid estimate of the number of principal investigators at each project, since this type of HQP has the largest economic impact. That being said, we also prepared tabulations and estimates of the other types of HQP. While the number and composition of HQP varied by project, we found that a total of 191 principal investigators were engaged in research at these five Big Science projects in 2010 (Table 11). We also estimated that these 191 principal investigators were supported by 50 post-doctoral research associates, 79 Ph.D. graduate students, 295 Masters level students and 211 undergraduate students. In total, we estimated that there were some 836 HQP involved in research at these five Big Science projects in 2010.

Table 11 Number of HQP engaged in research at Big Science projects in Canada

	TRIUMF	NEPTUNE	SNOLAB	ATLAS	Canadian Light Source	Total
Principal investigators	60	20	33	38	40	191
Post-doctoral research associates	0	18	19	13	--	50
Ph.D. graduate students	21	0	16	42	--	79
Masters graduate student	268	14	13	0	--	295
Undergraduate student	127	52	23	20	--	221
Total HQP	**475**	**104**	**104**	**113**	**40**	**836**

Source: Nordicity tabulations and estimates based on data from CANARIE and public reports.
'--' data not available from public reports

These tabulations of Big Science HQP provided the basis for estimating the economic impact associated with human capital formation supported by CANARIE. Before modelling this economic impact, we developed a rate of attribution to CANARIE; we developed this rate of attribution by examining the relative data-communications intensity of Big Science projects.

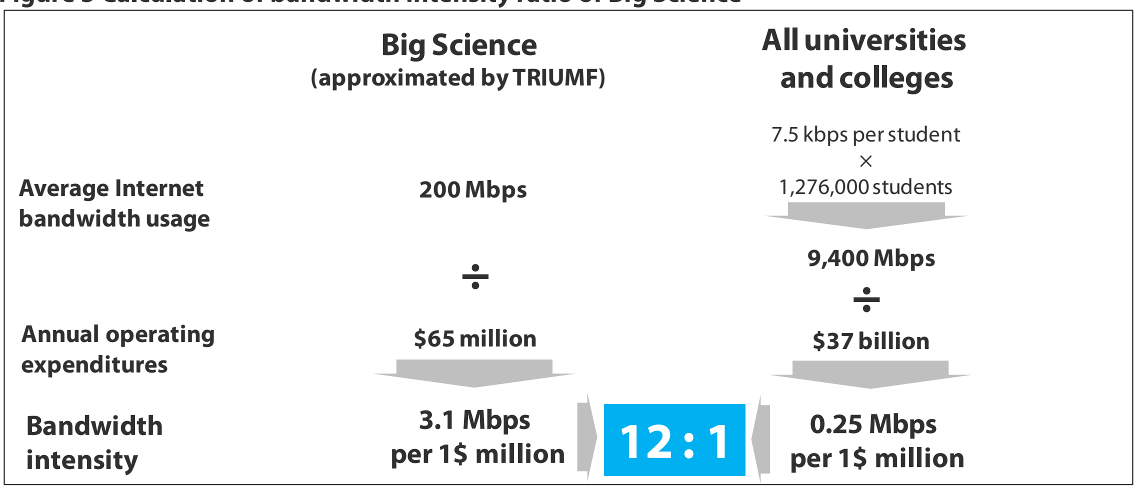
Attribution to CANARIE

The intensity of bandwidth use at Big Science projects is estimated to be 12 times higher than the overall average for all Canadian universities and colleges

According to Alindale Consultants (2010), one of the Big Science projects, TRIUMF, displayed an average bandwidth usage rate equivalent to 200 Mbps (megabits per second) in 2010 (Alindale Consultants 2010, p. 6). With an annual operating budget of approximately $65 million, TRIUMF's intensity of data use was equal to 3.1 Mbps per $1 million (Figure 5).

Alindale Consultants also reported that the average bandwidth use among all universities was 7.5 kbps (kilobits per second) per student in 2010 (Alindale Consultants 2010, p. 4). With just under 1.3 million students enrolled at Canadian universities and colleges in 2009 (Statistics Canada 2009a and 2009b), the overall average rate of bandwidth use was approximately 9,400 Mbps. Given that the annual operating budgets at Canadian colleges and universities totalled approximately $37 billion in 2009 (Statistics Canada 2009c), data intensity across universities was 0.25 Mbps per $1 million. In other words, the rate of data intensity at TRIUMF – representative of Big Science projects – was 12 times that across all post-secondary institutions.

Figure 5 Calculation of bandwidth intensity ratio of Big Science



Source: Nordicity calculations based on data from TRIUMF, AUCC and Statistics Canada.

We apply this 12:1 ratio to differences in the estimated data communications costs at educational institutions to arrive at an overall attribution rate for CANARIE. According to Statistics Canada's 2005 input-output tables, communications services accounted for 1.79% of the value of output in NAICS 61 *Educational Institutions* and 2.09% of the value of output in NAICS 54 *Professional, Scientific and Technical Services* (Figure 6). Since NAICS 61 also includes elementary and secondary schools, we consider NACIS 54 as well to arrive at an estimate of the value of communications services to output in the Canadian post-secondary sector. We concluded that communications services account for approximately 2.0% of the value of output.

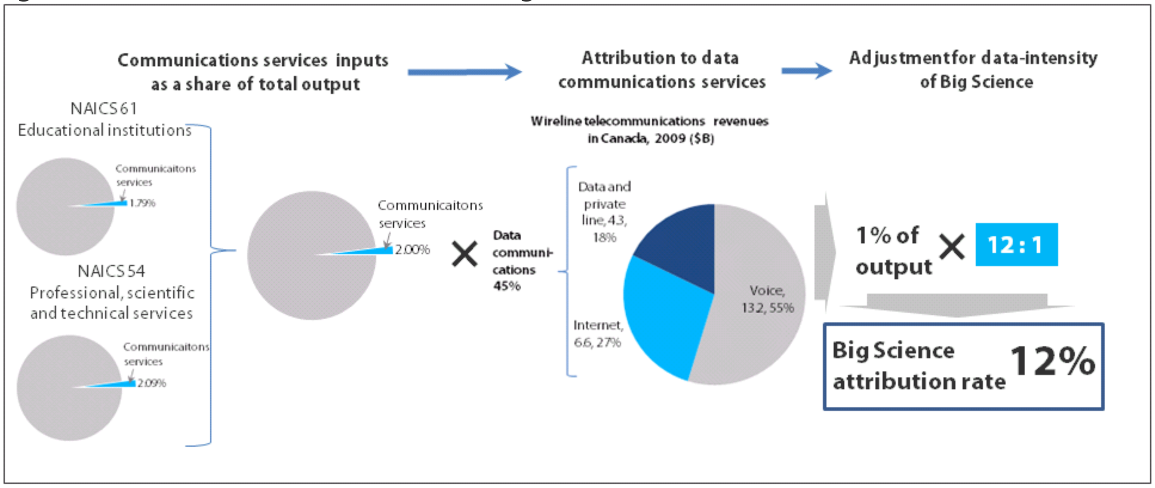
Communications services include voice as well as data communications. We used the relationship between the total revenues earned by Canadian telecommunications carriers to allocate this 2.0% rate to data and voice services.[6] According the data published by the Canadian Radio-television and Telecommunication Commission (CRTC), the combination of revenues from Internet services and private data lines comprise approximately 50% of total wireline communications services revenues (CRTC 2010, p. 113). On the basis of this revenue-share, we assumed that data communications contributed one percent of the value of output at Canadian post-secondary institutions. That is, one percent of the output of the post-secondary institution sector can be attributed to data communications.

Given that the intensity of data communications is 12 times higher at Big Science projects than across all post-secondary education, we adopted an attribution rate of 12% for CANARIE. We note that this rate is probably conservative. The research conducted for this study, by Clayman et al. (2009) and by Hickling

[6] We ignore wireless communications services, since the revenues earned in this segment are largely from consumer and business customers. We assume that cellular communications plays a minor role in the delivery of post-secondary education.

Arthurs Low (2008) demonstrates that CANARIE is critical to the success of big science projects (Hickling et al. 2008, pp. 7-8).

Figure 6 Calculation of attribution rate for Big Science



Source: Nordicity calculations based on data from Statistics Canada, Industry Canada, TRIUMF and AUCC.

An estimated 12% of the HQP engaged at Big Science projects can be attributed to the role of the CANARIE R&E network in enabling bandwidth-intensive research

Using this 12% attribution rate, we effectively attributed 12% of the value of the human capital attracted and retained by Big Science projects – i.e., HQP – to CANARIE. Bassanini and Scarpetta (2002) provide a robust model for translating this quantified human capital into economic outcomes. Bassanini and Scarpetta's model of the impact of human capital on productivity and economic growth was based on the average years of schooling among the working population. Essentially, their model demonstrated that real-GDP-per-capita[7] increases by 6% for every one year increase in the average number of years of schooling for the 25 to 64 population.

To leverage these findings, we modelled how the HQP attracted, retained and trained at Canada's Big Science projects affected the average level of schooling within the Canadian economy and then used the Bassanini and Scarpetta model to translate this increase in human capital into an estimate of the increase in real-GDP-per-capita. Our model assumed that each undergraduate possessed 16 years of education; each Masters graduate possessed 18 years of education; and each Ph.D. student possessed 21 years of education. We also assigned 21 years of education to each principal investigator and post-doctoral research associate.

Based on this approach we estimated that the HQP at Big Science projects, which can attributed to CANARIE, led to an annualized increase of 1,087 years in the aggregate level of education in the Canadian economy (Table 12). When these additional years of education are amortized across Canada's 18.6 million persons in the 25-64 age group, the result is a 30-minute increase in the level of education in the stock of human capital in Canada. This figure may sound like a very small amount, but as we will discover, even a small increase in the capital stock can have a large impact on the economy.

[7] Real-GDP-per-capita is calculated on the basis of the population aged 15 to 64.

Table 12 Impact of Big Science projects on human capital in Canadian economy

	Total HQP	Annualized totals†	HQP attributable to CANARIE (12%)††	Average years of education	Total increase in average years of education†††
Principal investigators	191	191	23	21	483
Post-doctoral research associates	50	50	6	21	126
Ph.D. graduate students	79	16	2	21	42
Masters graduate student	295	148	18	18	324
Undergraduate student	221	55	7	16	112
Total	**836**	**459**	**55**	**--**	**1,087**

Source: Nordicity tabulations and estimates based on data from CANARIE and public reports.
† To account for time required to train student, the number of undergraduate students has been divided by four, the number of Masters students has been divided by two, and the number of Ph.D students has been divided by five. Since post-doctoral research associates and principal investigators have already completed their academic training, no adjustment has been applied.
†† Equal to the annualized total multiplied by 12%.
††† Equal to the HQP attributable to CANARIE multiplied by the average years of education

The Big Science HQP attributable to CANARIE generated an estimated $100 million in annual GDP for the Canadian economy

Recall that Bassanini and Scarpetta (2002) found that real-GDP-per-capita (aged 15-64) increases by 6% for every one year increase in the average number of years of schooling for the 25-to-64 population. A 30-minute increase therefore leads to a $0.19 increase in Canada's real- GDP-per-worker of $55,976 (Table 13). When multiplied by the total number of workers in the Canadian economy (23.6 million), it means that CANARIE's role in Canada's Big Science projects led to a $4.6 million increase in real GDP on an annual basis. We multiplied this annual impact over the 30-year career of an HQP to estimate the aggregate future benefits; the result was a GDP impact of $137.2 million (30 × $4.6 million).

Table 13 Calculation of economic impact of CANARIE's role in Big Science projects

Line	Item	Source / Calculation	Amount
A	Increase in human capital (total years of education)	Table 12	1,087
B	Population (25 to 64)	Statistics Canada	18,608,940
C	Average per-person increase in human capital (years)	A÷B	0.000058
D	Average per-person increase in human capital (minutes)	C×365×24×60	30
E	Real GDP ($M)	Statistics Canada	1,325,085
F	Workforce (15 to 64)	Statistics Canada	23,672,481
G	Real GDP per working age population ($)	(E÷1,000,000)÷F	55,976
H	CANARIE's per capita impact ($)	C×6%×G	0.19
I	Aggregate real GDP impact ($)	H×F	4,574,505
J	Impact over 30-year career ($)	I×30	137,235,140
K	Present value of 30-year impact (discounted at 2.5%) ($)	J×0.73	100,181,652
L	Annualized impact ($)	K÷18	5,565,647

Source: Nordicity tabulations and estimates based on data from CANARIE, Statistics Canada and public reports.

Since these benefits are largely in the future, we discounted the estimate of $137.2 million using a real discount rate of 2.5%.[8] Therefore, the present value, in 2010 dollars, or CANARIE's role in Big Science

[8] The figure of 2.5% represents an estimate of the real inflation-adjusted time value of money. That is, it represents a long-run discount rate of 4.5% less a long-term rate of expected inflation of 2.0%. In the long-run, the real time value of money in the Canadian economy should approximate its long-term rate of real economic growth; in recent decades, real growth in the Canadian economy has approximated 2.5%.

projects, is estimated at $100.2 million. This total can be divided by CANARIE's 18 years of operation, so that the amount is reported on an annualized basis. On an annualized basis, therefore, CANARIE's role in Big Science projects led to an estimated GDP increase of $5.6 million (Table 13).

Other bandwidth-intensive research

Outside of Canada's five major Big Science projects, there are hundreds of other HQP also engaged in bandwidth-intensive research that is enabled by the CANARIE R&E network

CANARIE's impact on the attraction, retention and training of HQP goes beyond the Big Science projects. CANARIE also plays a prominent role in other areas of academic research with high bandwidth requirements. Clayman et al. (2009) concluded that approximately 523 principal investigators in Canada were engaged in bandwidth-intensive research (Clayman et al. 2009, p. 32). The authors further concluded that each principal investigator, in turn, attracted an average of two post-doctoral research associates and trained an average of 2.5 graduate students (Clayman et al. 2009, p. 32). After taking into account the 191 principal investigators at Big Science projects, the implication was that there was an additional 333 principal investors engaged in high-bandwidth research (523–191=333) in 2009. These 333 principal investigators were in turn supported by 666 post-doctoral research associates (333×2.0=666) and 833 Ph.D. students (333×2.5=833).

We use these estimates of the HQP involved in bandwidth-intensive research to estimate the economic impact associated with the role of CANARIE in attracting, retaining and training HQP in Canada. We adopt an approach similar to that applied to Big Science, however, we use an attribution rate of 6% rather than 12%. In total, we found that the bandwidth-intensive research underpinned by the CANARIE network attracted, retained and trained 70 HQP comprising 1,470 years of education (Table 14).

Table 14 Impact of bandwidth-intensive research on human capital in Canadian economy

	Total HQP	Annualized totals†	HQP attributable to CANARIE (6%)††	Average years of education	Total increase in average years of education†††
Principal investigators	333	333	20	21	420
Post-doctoral research associates	666	666	40	21	840
Ph.D. graduate students	833	166	10	21	210
Masters graduate student	--	--	--	18	--
Undergraduate student	--	--	--	16	--
Total	**1,829**	**1,164**	**70**	**--**	**1,470**

Source: Nordicity tabulations and estimates based on data from CANARIE and public reports.
† To account for time required to train student, the number of undergraduate students has been divided by four, the number of Masters students has been divided by two, and the number of Ph.D students has been divided by five. Since post-doctoral research associates and principal investigators have already completed their academic training, no adjustment has been applied.
†† Equal to the annualized total multiplied by 6%.
††† Equal to the HQP attributable to CANARIE multiplied by the average years of education.

The bandwidth-intensive research enabled by the CANARIE R&E network generated an estimated $137 million in annual GDP for the Canadian economy

This incremental increase in Canada's human capital stock of 1,470 years of education translates – based on the Bassanini and Scarpetta – into a present value economic impact of $137.2 million in GDP (in real 2010 dollars) (Table 15). On an annualized basis, the impact is $7.6 million in GDP.

Table 15 Calculation of economic impact of CANARIE's role in bandwidth-intensive research

Line	Item	Source / Calculation	Amount
A	Increase in human capital (total years of education)	Table 12	1,470
B	Population (25 to 64)	Statistics Canada	18,608,940
C	Average per-person increase in human capital (years)	A÷B	0.000079
D	Average per-person increase in human capital (minutes)	C×365×24×60	41
E	Real GDP ($M)	Statistics Canada	1,325,085
F	Workforce (15 to 64)	Statistics Canada	23,672,481
G	Real GDP per working age population ($)	(E÷1,000,000)÷F	55,976
H	CANARIE's per capita impact ($)	C×6%×G	0.26
I	Aggregate real GDP impact ($)	H×F	6,264,748
J	Impact over 30-year career ($)	I×30	187,942,434
K	Present value of 30-year impact (discounted at 2.5%) ($)	J×0.73	137,197,977
L	Annualized impact ($)	K÷18	7,622,110

Source: Nordicity tabulations and estimates based on data from CANARIE, Statistics Canada and public reports.

Summary

The CANARIE R&E network enables Canadian research institutions to attract, retain and train over 2,500 HQP, who, in turn, generate $237 million in incremental GDP for the Canadian economy over their research careers, or $13 million on an annual basis

As Canada's national R&E network, CANARIE plays an important role in supporting research initiatives at Canadian post-secondary institutions. These research initiatives help attract, retain and train HQP, who in turn, expand the productive capacity of the Canadian economy. CANARIE is most critical to Big Science projects. On the basis of the number of HQP associated with five of Canada's Big Science projects – TRIUMF, NEPTUNE, SNOLAB, ATLAS and Canadian Light Source – we estimated an annualized GDP impact of $5.7 million attributable to CANARIE. With respect to other bandwidth-intensive research, an estimated $7.6 million in GDP can be attributed to CANARIE. In total, CANARIE's role in Big Science projects and bandwidth-intensive research – which attracts, retains and trains HQP – generated an annualized GDP impact of $13.2 million.

Table 16 Summary of GDP impact associated with CANARIE's role in Big Science and bandwidth-intensive research in Canada (millions of real 2010 dollars)

Item	Total	Annualized
Big Science	100.2	5.7
Bandwidth-intensive research	137.2	7.6
Total	**237.4**	**13.2**

Source: Nordicity tabulations and estimates based on data from CANARIE, Statistics Canada and public reports.
Note: Some totals may not sum due to rounding.

3.2.4 Research productivity

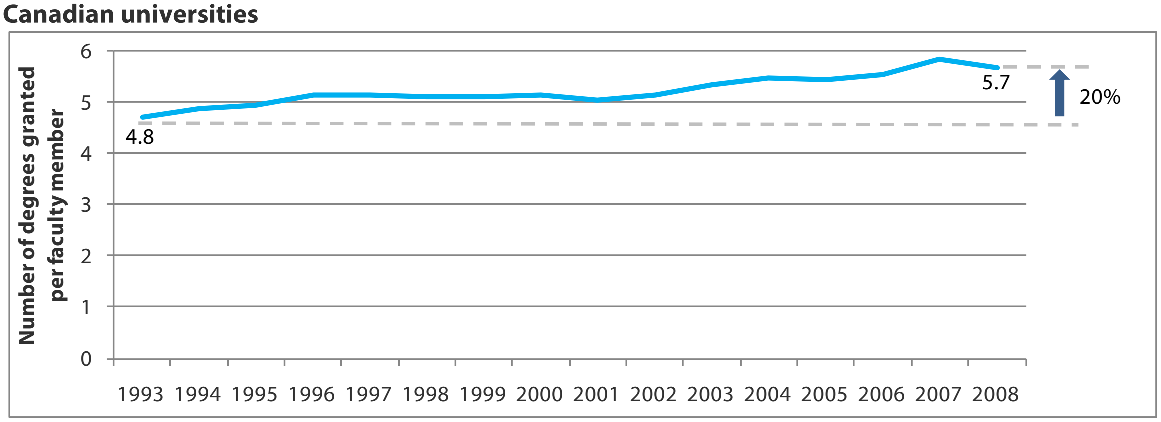
As an important element in the communications infrastructure of Canadian post-secondary institutions, the CANARIE R&E network also contributes to higher rates of productivity – generating additional HQP for the Canadian economy

CANARIE not only plays an important role in attracting, retaining and training HQP, by underpinning the data communications requirements of Big Science and bandwidth-intensive research, it also contributes to the data communications infrastructure that supports the general R&D endeavours at post-secondary institutions in Canada.

To estimate the impact that the CANARIE network has on R&D at post-secondary institutions and, in turn, the impact that this R&D has on the wider economy, we first assessed how the CANARIE network affected labour productivity at post-secondary institutions. In other words, we attempted to assess how the R&E network improved the rate at which post-secondary institutions produced graduates.

In general, we found that labour productivity did improve at Canadian universities between 1993 and 2008. Over this 18-year period, the number of graduate degrees produced per faculty member rose from 4.7 to 5.7 (Figure 7). In other words, on average, each faculty member was generating 20% more graduates in 2008 compared to 1993. This 20% increase in labour productivity, or 1.3% per annum, was in line with improvements in labour productivity across the overall Canadian economy. Statistics Canada reports that the annual rate of labour productivity growth across the business sector in Canada between 1996 and 2006 was 1.8% (Statistics Canada 2007, p. 9).

Figure 7 University faculty labour productivity, ratio of degrees granted to number of faculty, Canadian universities

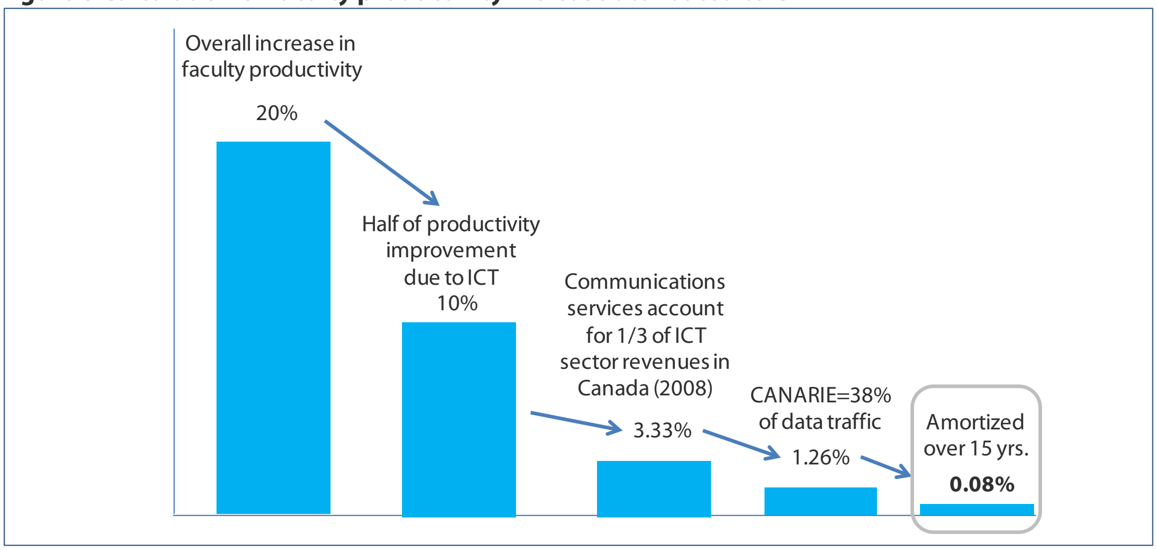


Source: Nordicity calculations based on data from Statistics Canada.

The next challenge was to attribute part of this 20% increase to the CANARIE R&E network. First, we assumed that at least one-half of the increase in productivity was due to information and communications technologies (ICTs). This assumption was consistent with research on the contribution of ICT to growth in labour productivity in the late 1990s and early 2000s. Gu (2010), Ho, Rao and Tang (2004) and Oulton and Srinivasan (2005) found that deepening of ICT capital in industries contributed approximately 40% to 50% of the increase in labour productivity in Canada, US and the UK during the late 1990s and early 2000s (Gu et al. 2010, p.12; Ho et al. 2004, p. 21; Oulton et al. 2005, p. 26).

We then needed to attribute this 10% productivity increase across various ICT environments: that is, we needed to separate the effect of computer hardware and software from broadband communications services. We used the communications services industries' share of ICT sector revenues to make this attribution. In 2008, communications services accounted for 33% of the $155 billion in revenues in Canada's ICT sector (Industry Canada 2009). ICT services, manufacturing and wholesaling accounted for the other two-thirds of revenues. On the basis of that revenue share, we assigned one-third of the 10%, or 3.33%, of the ICT-attributable productivity increase to broadband network communications services. In other words we assumed that university faculty experienced a 3.33% increase in productivity over the 20-year period due to the use of broadband Internet and networking.

Figure 8 Calculation of faculty productivity increase attributed to CANARIE



We then needed to attribute this 3.33% across CANARIE and commercial carriers. We used CANARIE's 38% average share of data traffic (i.e., as reported in our survey) to attribute 1.26% of the 3.33% to CANARIE. Finally, since this productivity increase appeared over a 15-year period, we divided 1.26% by 15. Accordingly, on an annualized basis, we attributed a 0.08% annual productivity increase directly to CANARIE.[9]

Of the 20% increase in Canadian faculty productivity observed between 1993 and 2008, approximately 1/16th , or 1.26%, can attributed to the role of the CANARIE network in the communications infrastructure at Canadian post-secondary institutions

Once again, we leveraged Bassanini and Scarpetta's model of the impact of human capital on productivity and economic growth to translate this increase in productivity into a measurement of economic impact. We modelled how a 0.08% increase each year in university-faculty productivity would change the average number of years of schooling in the working-age population. The model assumed that each undergraduate possessed 16 years of education; each Masters graduate possessed 18 years of education; and each Ph.D. graduate possessed 21 years of education.

Based on this modelling approach, we attributed approximately 140 to 200 graduates each year directly to CANARIE. These additional graduates added 80 to 90 minutes to the average level of education in the

[9] Applying the assumptions to the annual average rate of growth in labour productivity, 1.3%, would arrive at the same result, 0.08%.

stock of human capital. This figure may sound like a very small amount, but as we will discover, even a small increase in the capital stock can have a large impact on the economy.

Based on Bassanini and Scarpetta's model, a 90-minute increase in the human capital stock led to a 0.16% increase in real-GDP-per-worker. Again, this series of relationships only translated into a $0.60 increase in real GDP-per-worker. However, when multiplied by the total number of workers in the Canadian economy, it means that CANARIE directly led to an additional $13.9 million in real GDP on an annual basis. Over the 18-year period, 1993 to 2010, this lift in real GDP translated into an economic impact of $214.3 million in 2010 dollars.

Note that this amount included not only the private returns captured by graduates in terms of higher incomes, and by their employers in terms of higher profits, but also captured the spillover impact. This relationship suggests that other industries also captured benefits in terms of higher labour income and profits.

The higher research productivity enabled by the CANARIE network contributed to higher rates of HQP entering the Canadian workforce and generated $214 million in additional GDP for the Canadian economy, or $11.9 million in GDP on an annualized basis

In total, therefore, we estimated that the CANARIE network, through its general enabling effect on research productivity at Canadian post-secondary institutions and the related effect on the creation of human capital, led to an additional $214.3 million in GDP in the Canadian economy over the 18-year period, an additional $118.1 million in wages, and the creation of 130 FTEs (Table 17). On an annualized basis, the effect of the CANARIE network on general research productivity at Canadian post-secondary institutions generated real GDP of $11.9 million, wages of $6.6 million and 130 FTEs across the Canadian economy (Table 17).

Table 17 Annualized total economic impact of CANARIE network on faculty labour productivity, second order effects (real 2010 dollars)

	18-year total	Annualized
GDP ($M)	214.3	11.9
Wages ($M)	118.1	6.6
Average FTE cost ($ per annum)	50,486	50,486
FTEs	130	130

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

3.3 Third order effects

CANARIE has contributed to a more competitive market for advanced networks in Canada and has encouraged faster adoption of broadband applications among Canadians, thus leading to additional economic benefits across the Canadian economy

The economic benefits of the CANARIE network likely do not stop with its identifiable outputs. Previous evaluations have noted that the existence of CANARIE also generated significant pressure on commercial carriers to deploy their own advanced networks and to price these networks competitively (Hickling Corporation 1998, pp. 9-2; Hickling Arthurs Low 2006, pp. 3-9). Furthermore, CANARIE has played a role in facilitating the deployment of broadband community networks such as Alberta SuperNet, which are often instrumental in extending broadband service to rural communities.

CANARIE is not only a platform for advanced application development, but also an experiential platform for many educators. For example, when educators are able to use new broadband applications, such as multicasting on the CANARIE network, their understanding of the potential for broadband communications is heightened: this often leads to adoption of these new technologies on the broader Internet (Hickling Arthurs Low 2006, pp. 3-9). These supply- and demand-side pressures linked to CANARIE could manifest themselves in a number of ways: lower prices for dedicated bandwidth or more availability of dedicated bandwidth.

While these third-order effects are significant, they are extremely difficult to quantify, and even more difficult to attribute. One approach to understanding the magnitude of CANARIE's third order effects in the context of impacting commercial carriers' behaviour and general Internet use is to examine trends in broadband adoption. If an advanced network such as CANARIE does stimulate competition in dedicated bandwidth market and stimulate the use of broadband applications, then there should be some ultimate impact on overall broadband penetration.

More competitive bandwidth pricing and availability should ultimately increase overall broadband penetration, particularly when this competitive bandwidth permits community broadband networks to proliferate. The diffusion of new broadband applications – also facilitated by CANARIE – should also generate more demand for broadband connectivity. From an analytical perspective, however, it is very difficult to observe and quantify the impact of CANARIE on broadband adoption. There is the challenge of isolating the impact of CANARIE on Canada's broadband use.

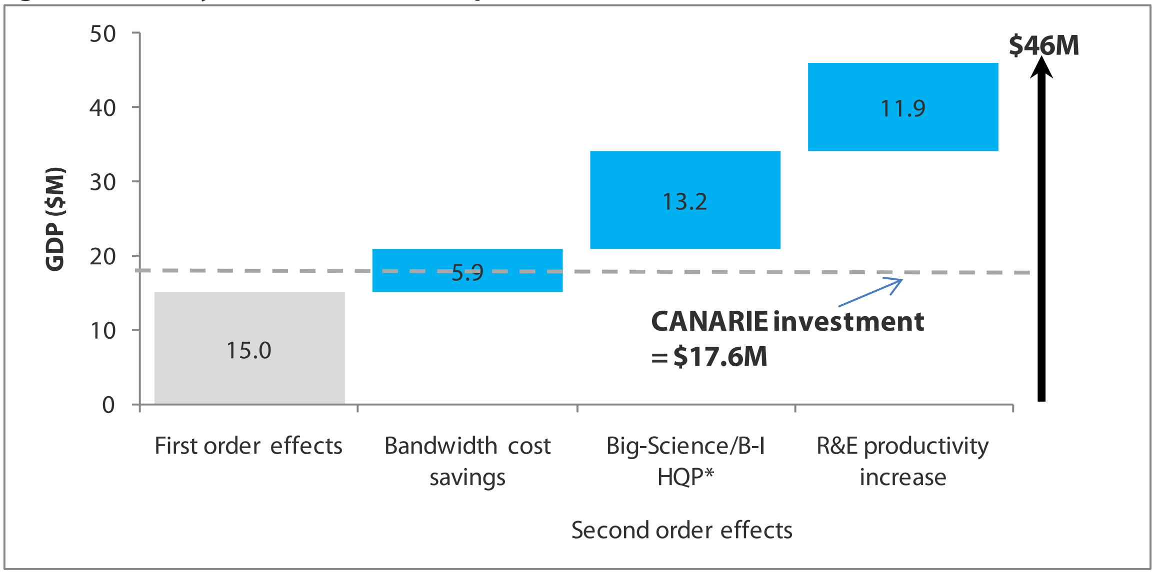
3.4 Summary of economic impact and return on investment

Between 1993 and 2010, each dollar invested in the operations of the CANARIE R&E network generated economic benefits of $2.61 in the form of GDP throughout the Canadian economy

In the preceding section we examined the economic benefits generated by CANARIE through its operation and administration of the R&E network it has pioneered. These economic benefits included not only the value of CANARIE labour and procurement expenditures, but also the bandwidth cost savings it generated for Canadian post-secondary institutions. More importantly, the R&E network contributed to attracting, retaining and training HQP, particularly HQP associated with Big Science projects and other areas of bandwidth-intensive research. As a key component of the broadband networks at Canadian universities, CANARIE also contributed to improved productivity at Canadian universities, thus helping to increase the number of HQP in the Canadian economy.

When all of these effects are considered together, we find that CANARIE's average annual investment of $17.6 million (between 1993 and 2010) in the operation and administration of the CANARIE network generated $46 million in GDP in Canada (Figure 9) on an annualized basis. This total economic impact included $15.1 million in GDP from first order affects and $31.0 million of GDP from second order effects. In other words, every dollar of CANARIE investment generated $2.61 in economic return (GDP) within the Canadian economy.

Figure 9 Summary of annualized GDP impact of CANARIE R&E network (real 2010 dollars)



Source: Nordicity estimates based on data from CANARIE and Statistics Canada.
*Highly qualified personnel (HQP) associated with Big Science projects and bandwidth-intensive (B-I) research.

4. Economic Benefits of CANARIE R&D Funding Programs

In this section, we turn our attention to the economic benefits of the R&D funding provided by CANARIE over the past 18 years. Alongside CANARIE's role as Canada's advanced R&E network, it has also administered various funding programs designed to further stimulate the development of innovative applications.

4.1 R&D funding programs

Between 1993 and 2010, CANARIE distributed $166 million in R&D funding to Canadian SMEs

During Phase I (1993-1995), CANARIE administered TD² through which it provided $12.8 million to small and medium-sized enterprises (SMEs) developing new information technology products, applications, software and services (Hickling Corporation 1998, pp. 1-3). TD² provided funding on a cost-shared basis to 42 projects (Hickling Corporation 1998, pp. 1-3). During Phase II, CANARIE administered TAD under which it distributed $27.7 million R&D funding on a cost-shared basis to SMEs developing new networking products and applications (Hickling Corporation 1998, pp. 1-3).

In accordance with its Phase III Contribution Agreement, CANARIE administered the AADP. AADP provided $68.8 million to companies and public institutions developing and deploying advanced applications for e-business, e-learning, e-health and intelligent systems. Along with AADP, CANARIE also managed or co-managed several other programs including the Learnware Program, CA*net Institute Project, the E-Content/ARIM Program, OLT Project and the Strategic Initiative Program. During Phase 4, CANARIE administered $30.6 million in funding.

Table 18 CANARIE R&D program funding

Phase	Funding program	Total funding expenditures ($M)	
Phase I	Technology Development, Technology Diffusion Program (TD²)	12.8	**12.8**
Phase II	Technology and Applications Development Program (TAD)	27.7	**27.7**
Phase III	Advanced Applications Development Program (AADP) BCE Learnware Program BCE Learnware Program Part II Non BCE Learnware Program Part II CA*NET Institute Project E-Content/Arim Project OLT Project Strategic Initiative Program	68.8 1.5 2.3 4.6 1.4 5.3 0.6 0.3	**84.9**
Phase 4	Phase 4 funding programs	30.6	**30.6**
Phase 5	Network-Enabled Platforms (NEP) GreenIT	9.2 0.5	**9.7**
		Total	**165.6**
		Total (real 2010 dollars)	**190.9**

Source: Nordicity tabulations based on data from CANARIE and Statistics Canada.

During the current Phase 5, CANARIE is administering four R&D funding programs: NEP, the GreenIT Program, and the Digital Accelerator for Innovation Research Program (DAIR).[10] As of the end of the 2009-10 fiscal year, CANARIE had distributed $9.2 million through NEP, $453,000 through the GreenIT Program. In total, CANARIE has distributed $9.7 million in funding during Phase 5. Over the 18-year period, 1993 to 2010, CANARIE distributed an estimated $165.6 million in funding for R&D (Table 18), or $190.9million in real 2010 dollars.

4.2 Financial leverage

The $166 million in R&D funding distributed by CANARIE attracted an additional $194 million in funding from other public- and private-sector sources, to bring the total value of CANARIE-sponsored R&D between 1993 and 2010 to close to $360 million

Many of CANARIE's R&D funding programs were administered on a cost-shared basis; as such, they attracted additional funding from other private- and public-sector sources. In particular, TD^2, TAD, AADP and OLT Project programs were all designed to attract additional private- and public-sector R&D funding. The financial data and documents supplied by CANARIE indicate that these four programs attracted an additional $193.6 million in R&D funding, or $239.0 million in 2010 dollars (Table 19).

Table 19 Financial leverage of CANARIE R&D program funding ($M)

Funding program	Funding from other sources 1993 to 2010
Technology Development, Technology Diffusion Program (TD^2)	40.2
Technology and Applications Development Program (TAD)	51.5
Advanced Applications Development Program (AADP)	101.3
OLT Project	0.6
Total	**193.6**
Total (real 2010 dollars)	**239.0**

Source: Nordicity tabulations based on data from CANARIE and Statistics Canada.

In total, therefore, CANARIE-administered programs led to overall R&D expenditures of $359.2 million, or $429.9 million in real 2010 dollars (Table 20). On an annualized basis, CANARIE-administered R&D programs led to $23.9 million in R&D activity.

Table 20 CANARIE program funding ($M)

	Total expenditures 1993 to 2010 (current dollars)	Total expenditures 1993 to 2010 (real 2010 dollars)	Annual average (real 2010 dollars)
Funding provided by CANARIE	165.6	190.9	10.6
Funding provided by other sources	193.6	239.0	13.3
Total funding of CANARIE-sponsored R&D projects	359.2	429.9	23.9

Source: Nordicity tabulations based on data from CANARIE

[10] DAIR is a $3 million pilot program launched in December 2010. Since it was launched during the 2010-11 fiscal year, we exclude it from this analysis.

4.3 First order effects

CANARIE-sponsored R&D generated $270 million in GDP and wages between 1993 and 2010, which, in turn, supported 170 direct FTEs in R&D activity

In this section, we estimate the first order effects associated with CANARIE's R&D program funding. We estimate the direct, indirect and induced economic impacts generated by the total R&D funding on CANARIE-sponsored projects.

To determine the direct GDP generated by CANARIE-sponsored R&D, we needed a proxy for the portion of funding devoted to labour costs. We reviewed Statistics Canada's 2004 employment multipliers for NAICS 5413 *Architectural, Engineering and Related Services* and NAICS 5415 *Computer Systems Design and Related Services;* when combined with average salary data, they indicated that approximately 63% of output in these industries went to labour. This wage share was consistent with information in CANARIE's *2009-10 Annual Report to the Minister of Industry*, which indicated that between 90% of NEP expenditures and 71% of NEP-2 expenditures went to labour. We further assumed that wages were the only source of value added in the activity of CANARIE-sponsored R&D.

Based on these assumptions, CANARIE-sponsored R&D generated $269.8 million in GDP and wages between 1993 and 2010, which, in turn, supported 170 direct FTEs in R&D activity (Table 21). On an annual basis, CANARIE-sponsored R&D generated $15.0 million in GDP and wages, and supported 170 direct FTEs in R&D activity.

Table 21 Direct economic impact of CANARIE-sponsored R&D (real 2010 dollars)

	18-year total, 1993 to 2010	Annualized
Output (i.e., operating expenditures) ($M)	429.9	23.9
GDP ($M)	269.8	15.0
Wages ($M)	269.8	15.0
Average FTE cost ($ per annum)	89,919	89,919
FTEs	170	170

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

4.3.1 Spin-off and total economic impact

After taking into account the spin-off economic impacts of CANARIE-sponsored R&D, the total annualized gross economic impact was $31 million in GDP and 340 FTEs

CANARIE-sponsored R&D also generates a spin-off economic impact comprised of indirect and induced economic impacts. Using Statistics Canada's 2005 input-output tables and Nordicity's own induced economic impact multiplier (see Appendix A) we modelled the overall spin-off economic impact of CANARIE-sponsored R&D. Our modelling of the indirect impact essentially assumed that the profile of indirect expenditures – purchases of goods and services – mirrored that of non-labour expenditures in NAICS 54 *Professional, Scientific and Technical Services* industry.

Table 22 details the spin-off and total economic impact generated by CANARIE-sponsored R&D over the 18-year period, 1993 to 2010. After estimating and adding the spin-off economic impact, CANARIE-sponsored R&D activity generated a total of $553.9 million in GDP in the Canadian economy, along with $423.9 million in wages and 340 FTEs.

Table 22 Spin-off and total economic impact of CANARIE operations, 1993 to 2010 (real 2010 dollars)

	Direct	Spin-off		Total
		Indirect	Induced	
GDP ($M)	269.4	44.7	239.8	553.9
Wages ($M)	269.4	25.2	129.3	423.9
Average FTE cost ($ per annum)	89,919	50,486	50,486	--
FTEs	170	30	140	340

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

On an annualized basis, CANARIE-sponsored R&D activity generated a total economic impact equivalent to $30.8 million in GDP and $23.6 million in wages, which supported 340 FTEs (Table 23).

Table 23 Annualized total economic impact of CANARIE-sponsored R&D activity, 1993 to 2010 (real 2010 dollars)

	18-year total	Annualized
GDP ($M)	553.9	30.8
Wages ($M)	423.9	23.6
FTEs	340	340

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

4.3.2 Net economic benefit

After taking into account the deadweight loss of the taxes required to fund CANARIE-sponsored R&D, the net economic was equal to $27 million in GDP and 300 FTEs

As with the measurement of the economic impact of CANARIE's network investments, some allowance needs to be made for the deadweight loss associated with the tax revenues required to finance CANARIE's R&D funding programs. To calculate the deadweight loss we apply the deadweight loss rate of 0.32 from Baylor and Beauséjour (2004) to the sum of CANARIE's R&D funding, $190.9 million (real 2010 dollars).

After taking into account the deadweight loss associated with the taxation required to provide the financial resources for CANARIE's R&D funding programs between 1993 and 2010, we conclude that the net economic benefit of the first order effects was equal to $488.6 million in GDP (Table 24). This GDP included $373.9 million in wages. On an annualized basis, the net economic impact of the first-order effects of CANARIE-sponsored R&D projects generated $27.1 million in GDP, $20.8 million in wages and 300 FTEs.

Table 24 Deadweight loss of taxation and net economic impact of first order effects of CANARIE-sponsored R&D (real 2010 dollars)

	Gross economic impact (1993-2010)	Deadweight loss of taxation†	Net economic impact	Annualized net economic impact
GDP ($M)	553.9	65.4	488.6	27.1
Wages ($M)	373.9	50.1	373.9	20.8
FTEs	340	40	300	300

Source: Nordicity estimates based on data from CANARIE, Statistics Canada, and Baylor and Beauséjour (2004).
† Represents the efficiency loss (opportunity cost) to the Canadian economy of raising $190.9 million in federal tax income (real 2010 dollars) to fund CANARIE's R&D programs and operations between 1993 and 2010.

4.4 Second order effects

The commercialization of products and services developed as a result of CANARIE-sponsored R&D generated significant economic benefits for the companies that develop them as well as the wider economy

The more profound economic benefits of CANARIE's R&D funding arise from the products and services that were ultimately commercialized from this research. In this section, we estimate the economic benefits from these commercialized products and services. The commercialization of these innovative products and services provided private returns to the companies that developed them; they also had significant spillover effects across the Canadian economy.

4.4.1 Private returns (product sales)

Products and services developed from CANARIE-sponsored R&D generated total sales of $178 million between 1996 and 2005

The R&D activity supported by CANARIE ultimately has effects throughout the Canadian economy primarily through two channels: private returns and spillover effects. In this section we address and quantify the private returns from CANARIE-sponsored R&D.

Some portion of R&D leads to the creation of knowledge. The researchers and SMEs engaged in the R&D can patent this knowledge to form intellectual property (IP). This IP forms the basis for the development of new products and services. Researchers and SMEs can earn revenues from these products and services either through direct sales or through the licensing of the relevant IP to third parties that produce and sell the new products and services. These revenues form the private returns from R&D, since the SMEs engaged in the R&D capture the vast majority of the economic benefits.

To quantify the private returns from CANARIE R&D, we summed the product revenues reported to CANARIE in accordance with the royalty system it had in place for certain of its R&D funding programs. TAD, AADP, Learnware, and the E-content program all had royalty provisions incorporated into their funding contracts. These royalty provisions required funding recipients to remit between 2% and 20% of product revenues up to maximum multiple of CANARIE funding (typically 1.25× CANARIE funding). According to documents supplied by CANARIE, the products developed through these four funding programs generated total sales of $177.8 million[11] between 1996 and 2005, or $231.4 million in real 2010 dollars.

These sales revenues generate direct and spin-off economic impacts. The direct economic impact includes the increased GDP, wages and employment in the industries that produce and sell the new products or services. The spin-off impact includes the impact associated with those producer industries' purchases of inputs from supplier industries; it also includes the economic impact associated with the re-spending of household income that can be traced back to the higher employment in the producing and input-supplying industries.

To estimate the direct economic impact associated with the private returns, we converted the sales revenues into estimates of direct GDP using Statistics Canada's input-output tables for NAICS 54 *Professional, Scientific and Technical Services*. We selected this industry because it includes the *Computer*

[11] This amount should be considered a conservative estimate because it excludes certain programs, and for the TAD Program, there was a time limit on the royalty-remittance period.

Systems Design and Related Services Industry (NAICS 5415), which we believe most closely resembles the output of companies supported by CANARIE R&D funding.

The commercialization of CANARIE-sponsored R&D led to a total GDP impact of $308 million between 1993 and 2010, and generated 150 FTEs

According to Statistics Canada's input-output tables, a one dollar increase in output in NAICS 54 results in a $0.61 increase in GDP and a $0.44 increase in wages. Based on these ratios, the product and service revenues of $231.4 million generated $140.4 million in direct GDP, $100.8 million in direct wages and 60 FTEs. These revenues generated an additional spin-off impact of $167.4 million in GDP, $84.8 million in wages and 90 FTEs. In total, the $231.4 million in downstream revenues generated $307.9 million in GDP, $185.6 million in wages and 150 FTEs within the Canadian economy.

Table 25 Economic impact of private returns from CANARIE-sponsored R&D (real 2010 dollars)

	Direct	Spin-off impact	Total economic impact
Output ($M)	231.4	--	231.4
GDP ($M)	140.4	167.4	307.9
Wages ($M)	100.8	84.8	185.6
Average FTE cost ($ per annum)	89,919	50,486	--
FTEs	60	90	150

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

On an annualized basis, the direct economic impact associated with the product and service revenues originating from IP developed with the support of CANARIE's R&D funding was equal to $17.1 million in GDP. The direct economic impact also generated wages of $10.3 million on an annualized basis and led to the creation of 150 FTEs (Table 26).

Table 26 Total and annualized economic impact of private returns from CANARIE-sponsored R&D (real 2010 dollars)

	Total economic impact (1993 to 2010)	Annualized impact
GDP ($M)	307.9	17.1
Wages ($M)	185.6	10.3
FTEs	150	150

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

4.4.2 Spillover effects

The economic benefits of new products and services often accrue to companies and individuals that do not first commercialize them; these are the spillover effects of innovation

The economic impact of the new products and services attributable to CANARIE-sponsored R&D also has a spillover effect as these products and services and the IP associated with them contribute to innovation and productivity improvement in other sectors of the economy. While R&D is conducted within one institution or company, R&D spillovers (e.g., via informal social networks, reverse engineering, formal information exchanges such as publications) move beyond the boundaries of organizations and can be beneficial to a large number of external individuals and companies. The R&D spillovers have a significant impact on economic growth over the long run, and this is particularly true for publicly funded research.

Quantifying the spillover effects of R&D can be challenging; however, there is a large body of empirical research on the social rate of return from R&D expenditures. In contrast to the private rate of return, this social rate of return captures both the economic benefits of the private returns accrued by the researchers (e.g., higher incomes) and firms (e.g., higher profits) and companies that develop the R&D outputs, but also captures the positive economic spillovers (e.g., new products, higher sales, higher productivity, price decreases) at other firms and in other sectors.

Existing academic research suggests that the social rate of return from R&D is very high: in the range of 30% to 40%. Mansfield (1991) estimated that the social rate of return from academic R&D in the US was 28%. Mansfield (1992) subsequently updated this estimate to 40%. Research indicates that Canada's social rate of return on R&D may be somewhat lower. According to Martin (1998), a 30% rate of return may be considered a reasonable approximation of the social rate of return for Canadian university R&D. Martin (1998) found that a simulation involving a yearly R&D investment of 1.5% of GDP starting in 1971 (the historical average for Canada), a social rate of return of 30% and a useful life of seven years for innovations, causes Canadian GDP to grow at a rate of 3.25% by 1993, which is exactly what happened.

Social rate of return

The **private rate of return** refers to the relationship between the costs borne by private economic agents (e.g., a student or firm) and the benefits that these private economic agents accrue. The **social rate of return** refers to the relationship between the costs borne by society (i.e., citizens or taxpayers) and the benefits that society accrues from these costs. For example the costs of post-secondary education are often shared between students (i.e., private economic agents) and taxpayers. Both parties share the benefits as well. Students earn higher incomes, while society benefits from a more productive workforce, educated electorate and potential lower rates of crime. All of these benefits – which can be expressed in monetary terms –comprise the social return.

Research indicates that R&D expenditures yield a social rate of return – which captures both private returns and spillover effects – of approximately 30%

We elect to use this 30% social rate of return to estimate the spillover effects of R&D outputs from CANARIE-sponsored R&D, because it permits us to derive the economic value on the basis of the value of the input, i.e., R&D expenditures. That being said, we recognize that this social rate of return, in theory, applies to all R&D activity and is not directly applicable to individual R&D projects or specific streams of R&D. In order to ascertain the applicability of the 30% social rate of return to CANARIE-sponsored R&D, we sought to benchmark the performance of CANARIE-sponsored R&D. Implicit in our performance benchmarking exercise was the assumption that the social rate of return of R&D activity is closely correlated with rate of outputs generated by that R&D activity. That is, R&D activity that generates more inventions, patents, or direct downstream revenues is likely to have a higher rate of diffusion and adoption, and thereby, is more valuable to the economy.

Given the type of data available to us, we were only able to benchmark CANARIE-sponsored R&D in terms of its downstream revenues. As such, we conducted the performance benchmarking on the basis of the ratio of direct sales to R&D expenditures. We compared the sales-to-R&D ratio for CANARIE-sponsored projects to ratio observed across all academic R&D. On the basis of the comparison, we then determined if a social rate of return that is lower or higher than 30% should be applied to CANARIE-sponsored R&D.

The only benchmarking data we could obtain was from the Association of University Technology Managers' (AUTM) 1997 survey of R&D commercialization at academic institutions in the US and Canada. The results of this survey provided estimates of R&D expenditures in 1997 at 148 academic institutions, and the value of sales in the previous year related to these institutions' licensed products. The results indicated that, across all reporting institutions, the sales-to-R&D ratio was 0.99. Gu and Whewell (1999) use the AUTM survey results to estimate the sales associated Canadian institutions' licensed products. They estimate sales at $565 million (in Canadian currency). This estimate was equal to approximately 40% of the R&D expenditures reported by the Canadian institutions – a sales-to-R&D ratio of 0.40 (Table 27).

We found that projects supported by CANARIE displayed a sales-to-R&D ratio of 0.58. The fact that CANARIE-sponsored R&D displayed a higher sales-to-R&D ratio suggests that it might have yielded an even higher social rate of return than the rate of 30% associated with university R&D. Nevertheless, given that the R&D sales performance of CANARIE projects was largely consistent with those of Canadian academic institutions in 1997, and was not order-of-magnitudes lower, we adopted the 30% social rate of return to model the spillover effects of CANARIE-sponsored R&D.

Table 27 R&D performance benchmarking

	Total (US$)	Canada (C$)[i]	CANARIE[ii]
Sales related to licensed products (1996[iii]) ($M)	20,600	565[v]	17.8
R&D expenditures (1997[iv]) ($M)	20,904	1,422	30.5
Sales-to-R&D ratio	0.99	0.40	0.58

Source: Nordicity calculations based on data from AUTM Survey 1997 as reported in Gu and Whewell (1999).
Notes:
i. All amounts from the AUTM survey were originally reported in US currency; they have been converted to Canadian currency at the 1997 average exchange rate of 1.36C$/US$.
ii. CANARIE data correspond to the annual average for reported revenues and funding over a ten-year period for funding programs with royalty provisions. Over the ten-year period, CANARIE provided $111.1 million in funding to projects. These projects attracted $193.6 million in additional funding and generated $177.8 million in revenues through 2006-07.
iii. Institutions surveyed in 1997 reported sales related to licensed products for 1996.
iv. R&D expenditures in 1997 reported by institutions surveyed in 1997.
v. This figure was estimated by Zu and Whewell (1999).

CANARIE-sponsored R&D between 1993 and 2010 generated over $900 million in social return – private returns and spillover effects – for Canada

A social rate of return of 30% over a seven-year time period implies that GDP will be $5.27 times larger at the end of the period for every $1.00 of R&D expenditure. When we apply this GDP multiplier to the total CANARIE-sponsored R&D expenditures of $190.9 million, we arrive at a total GDP impact of $1.0 billion (Table 28). If we discount this future stream of economic benefits at a time-value-of-money of 2.5%,[12] the present value of the future benefits would be worth approximately $913 million.

This $913 million in incremental GDP yields $493.2 million in wages and 540 FTEs over the 18-year period (Table 28). On an annualized basis, CANARIE-sponsored R&D led to $50.7 million of incremental GDP and $27.4 million in incremental wages.

[12] The figure of 2.5% represents an estimate of the real inflation-adjusted time value of money. That is, it represents a long-run discount rate of 4.5% less a long-term rate of expected inflation of 2.0%. In the long-run, the real time value of money in the Canadian economy should approximate its long-term rate of real economic growth; in recent decades, real growth in the Canadian economy has approximated 2.5%.

Table 28 Calculation of social return of CANARIE-sponsored R&D activity, 1993 to 2010 (real 2010 dollars)

	18-year total	Annualized
CANARIE-sponsored R&D expenditures ($M)	190.9	10.6
GDP-R&D multiplier (based on 30% social rate of return and seven-year return period)	5.27	5.27
GDP ($M)	1,007.0	55.9
Present value of GDP ($M)	913.4	50.7
Wage ratio	0.54	0.54
Wages	493.2	27.4
Average FTE cost ($ per annum)	50,486	50,486
FTEs	540	540

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

On an annualized basis, the spillover effects from the commercialization of CANARIE-sponsored R&D was approximately two times the private return - $34 million vs. $17 million

Since the social rate of return already incorporates private returns from R&D, we deducted the economic impact of private returns to arrive at an estimate of the spillover effects. Based on this approach, we found that the spillover effects of CANARIE-sponsored R&D dominated the private returns. On an annualized basis, the spillover effects associated with CANARIE-sponsored R&D were equal to $33.6 million in GDP and $17.1 million in wages; these wages led to the creation of 390 FTEs (Table 29).

Table 29 Calculation of spillover effects of CANARIE-sponsored R&D activity, annualized basis, 1993 to 2010 (real 2010 dollars)

	Total social return	Private return	Spillover effects
GDP ($M)	50.7	17.1	33.6
Wages ($M)	27.4	10.3	17.1
FTEs	540	150	390

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

4.5 Summary and Attribution

In the following section we sum the first order and second order effects to arrive at an estimate of the overall gross impact of CANARIE-sponsored R&D activity. We then determine and calculate the portion of this gross economic impact that can attributed to CANARIE.

4.5.1 Gross impact

Between 1993 and 2010, CANARIE-sponsored R&D generated a total economic impact of $1.4 billion in GDP for the Canadian economy, or $78 million on an annual basis

We can add the economic impact of the first order and second order effects to arrive at an estimate of the overall economic impact of CANARIE-sponsored R&D. Over the 18-year period, 1993 to 2010, CANARIE-sponsored R&D generated a total economic impact of just over $1.4 billion of GDP and $867.1 million in wages (Table 30). These wages generated 840 FTEs. On an annualized basis, the total impact was equal to $77.9 million in GDP and $48.2 million in wages.

Table 30 Summary of first order and second order effects, 1993 to 2010 (real 2010 dollars)

	First order effects	Second order effects	Total impact	Total impact annualized
GDP ($M)	488.6	913.4	1,402.0	77.9
Wages ($M)	373.9	493.2	867.1	48.2
FTEs	300	540	840	840

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

4.5.2 Attribution to CANARIE

Of the total economic impact of CANARIE-sponsored R&D, $617 million in GDP (44%) and 370 FTEs can be attributed to CANARIE, with the balance attributable to other R&D sponsors

While CANARIE has played a key role in stimulating R&D activity through its administration of R&D funding programs, other economic actors also played a role in the development and commercialization of the innovative products and services associated with CANARIE-supported projects. In particular, we note that many of CANARIE's R&D funding programs were cost-shared programs whereby other parties contributed project funding. As such 100% of the economic impact associated with the private returns and spillover effects should not be attributed solely to CANARIE; some rate of attribution is required.

We used CANARIE's share of project funding to approximate its rate of attribution. Between 1993 and 2010, the cost-sharing aspect of many of its programs meant that CANARIE accounted for 44% of total project funding (see Table 20). When this attribution rate of 44% was applied to the estimate of gross economic impacts, it implies that CANARIE-sponsored R&D activity generated an annualized GDP impact of $34.3 million (in real 2010 dollars) and wages of $21.2 million. These wages led to the creation of 370 FTEs on an annualized basis.

Table 31 Economic benefits of CANARIE-sponsored R&D activity attributable to CANARIE, annualized basis, 1993 to 2010 (real 2010 dollars)

	Total impact	Annualized
GDP ($M)	616.9	34.3
Wages ($M)	381.5	21.2
FTEs	370	370

Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

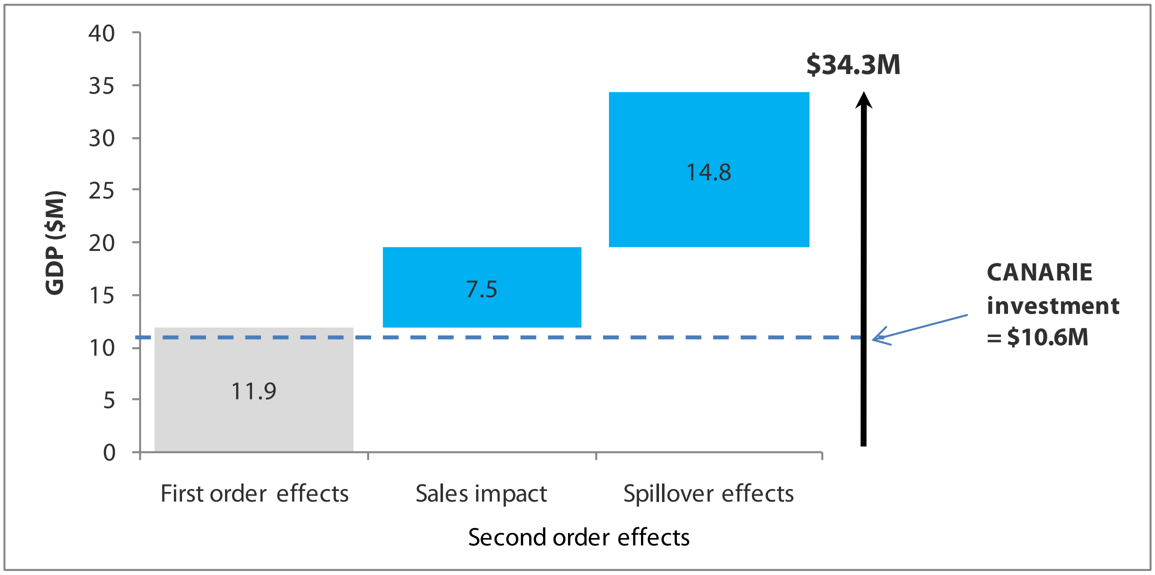
4.6 Summary of economic impact and return on investment

Between 1993 and 2010, each dollar of R&D funding from CANARIE generated economic benefits of $3.24 in GDP in the Canadian economy

Between 1993 and 2010, CANARIE distributed an annual average of $10.6 million in R&D funding. The first order effects of this R&D funding generated annualized GDP of $11.9 million. The second order effects from this R&D funding were worth $22.3 million in GDP in Canada.

This incremental GDP included $7.5 million in GDP associated with sales of new products and services (i.e., private returns), and $14.8 million in GDP due to increased rates of innovation and productivity growth in the Canadian economy arising from these new products or from the R&D activity itself (i.e., spillover effects). In other words, every dollar of CANARIE R&D funding generated $3.24 in economic return (GDP) within the Canadian economy.

Figure 10 Summary of economic impact and return on investment from CANARIE-sponsored R&D (annualized, real 2010 dollars)



Source: Nordicity estimates based on data from CANARIE and Statistics Canada.

5. Summary of Key Findings

Every dollar of investment in the Canadian R&E sector through CANARIE generated $2.85 in GDP for the Canadian economy

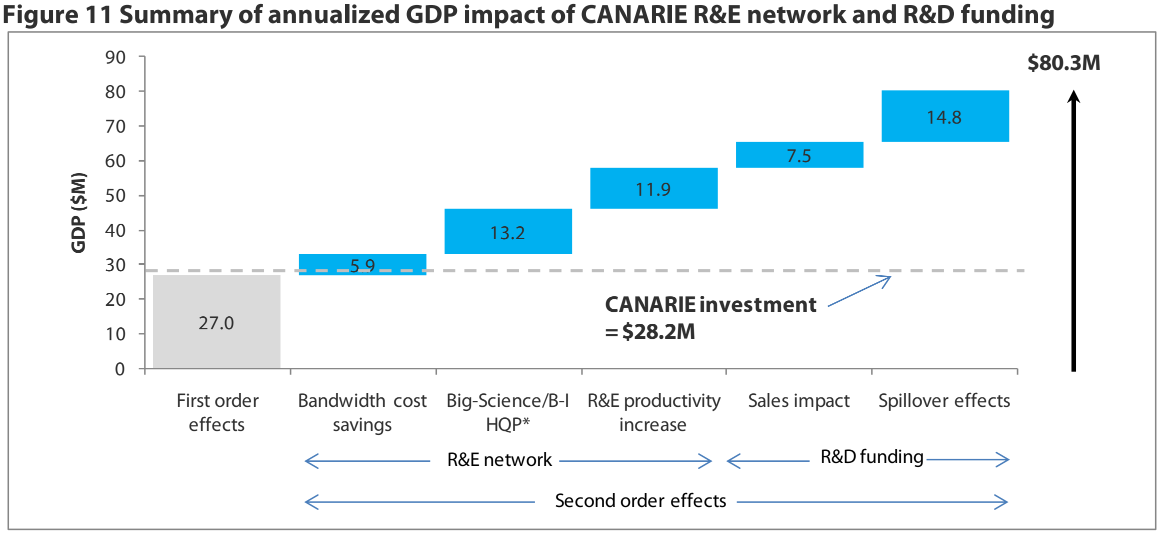
In its role as an R&E network, CANARIE has the potential to generate significant economic benefits for the Canadian economy. CANARIE also affects Canada's economic growth largely through its facilitation and funding of R&D.

In the preceding analysis, we examined, separately, the economic impact of CANARIE through its role as an R&E network and as a distributor of R&D funding. As an R&E network, CANARIE stimulated demand for telecommunications equipment, telecommunications services and labour to operate and administer the R&E network. More importantly, it was a critical element in many of Canada's Big Science projects and crucial to much of the bandwidth-intensive research at Canadian academic institutions. The CANARIE R&E network also played a role in improving the productivity of Canadian university faculty, thus generating additional HQP and raising Canada's stock of human capital at a faster rate than would have been the case without a CANARIE. This effect on the stock of human capital, subsequently, had a significant impact on per-capita-GDP.

Over the course of its 18-year history, CANARIE was also a source of R&D funding within the Canadian R&D community. This funding helped numerous Canadian SMEs develop and commercialize innovative products and services. CANARIE R&D funding also generated income within the Canadian economy. To estimate the economic benefits of CANARIE's R&D funding, we referred to existing empirical research pointing to a 30% social rate of return on university R&D in Canada.

When the value of the economic benefits of the CANARIE R&E network and R&D funding are added together, we find that CANARIE generated an estimated $80.3 million per annum (in real 2010 dollars) in GDP within the Canadian economy. This total GDP impact included $27.0 million in first order effects and $53.3 million in second order effects.

Figure 11 Summary of annualized GDP impact of CANARIE R&E network and R&D funding



Source: Nordicity estimates based on data from CANARIE and Statistics Canada.
*Highly qualified personnel (HQP) associated with Big Science projects and bandwidth-intensive (B-I) research.

The second order GDP effects were comprised of $5.9 million in Internet bandwidth cost savings; $13.2 million attributable to the value of HQP attracted, retained and trained through Big Science and bandwidth-intensive research; $11.9 million attributable to productivity improvements at Canadian universities; $7.5 million generated from the commercialization of CANARIE-sponsored R&D; and $14.8 million from the spillover effects of that R&D activity.

Considering that CANARIE's operational expenditures and R&D funding averaged a combined $28.2 million per annum between 1993 and 2010, the economic benefits analysis indicates that **every dollar of investment in the Canadian R&E sector through CANARIE generated $2.85 in GDP for the Canadian economy.**

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Appendix A: Methodology

Induced economic impact multiplier

One of the biggest challenges or considerations in preparing an economic impact analysis is the development of the induced impact multiplier. The induced economic impact arises when households that earn income at the direct and indirect impacts stages re-spend their income throughout the economy. While Statistics Canada's input-output tables do provide the basis for calculating the indirect economic impact of an economic shock, they do not inform the calculation of the induced economic impact.

In the absence of data and multipliers from Statistics Canada, economists often rely upon propriety macroeconometric models to estimate the induced economic impact. A macroeconometric model was not available to us; so we developed a simple approach for deriving an induced economic impact multiplier, which follows the general principle of induced economic impacts.

As noted, the induced economic impact arises from re-spending that occurs in the economy. This rate of re-spending is a function of the marginal propensity to consume (MPC) within an economy. That is, the percentage of total income that households spend on the purchase of goods and services. For example, if households' MPC is 0.7 then they will spend 70% of their income on the purchase of goods and services. The recipients of the income from these purchases will then spend 70% of their income on the purchases of goods and services, and so on. The resulting mathematical series, 0.7×0.7×0.7×0.7×…, can be expressed as an infinite geometric sum that is equal to 1/(1-0.7), or approximately 3.33.

With an estimate of the MPC, one can derive an induced impact multiplier by using the following formula: 1/(1-MPC). We use this approach with an adjustment for imports to arrive at an induced impact multiplier for the Canadian economy.

Table 32 outlines the derivation of the induced impact multiplier. After taking into account the MPC in the Canadian economy (0.69) and the marginal propensity to import (MPM), we arrive at an induced impact multiplier of 1.83. In other words, each dollar of household income (wages) at the direct-impact and indirect-impact stages yields $1.83 of output at the induced impact phase.

Table 32 Derivation of induced-impact multiplier

Line	Item	Notes/ Formula	Amount
1	Personal disposable income, 4th quarter 2010 ($B)	1	1,025.9
2	Estimated personal income	2	1,231.8
3	Personal expenditure on goods and services, 4th quarter 2010 ($B)	1	853.2
4	Marginal propensity to consume (MPC)	Line 3÷Line 2	0.69
5	Gross domestic product at market prices, 2010 ($B)	3	1,629.5
6	Imports, 2010 ($B)	3	428.4
7	Marginal propensity to import	Line 6÷Line 5	0.26
8	MPC –MPM	4	0.43
9	Induced impact output multiplier	1÷(MPC–MPM)	1.83

Source: Nordicity calculations and estimates based on data from Statistics Canada.
Notes:
1. Source: Statistics Canada, Economic indicators, by province and territory, http://www40.statcan.ca/l01/cst01/indi02a-eng.htm.
2. Personal disposable income is estimated by multiplying reported personal disposable income by 20% to account for personal taxes.
3. Source: Statistics Canada, "Real gross domestic product, expenditure based," downloaded at http://www40.statcan.ca/l01/cst01/econ04-eng.htm.
4. We subtract the MPM from the MPC in order to proxy to portion of household re-spent within the Canadian economy.

We can apply the GDP and wage ratios from the Statistics Canada input-output tables to ascertain the induced impact GDP and wages that each dollar of income at the induced impact phase. In this case, we use the economy-wide ratios rather than any industry specific ratios. The economy-wide GDP ratio of

0.49 implies that each dollar of output generates 90 cents of induced impact GDP. The wage ratio of 0.26 implies that the each dollar of output shock generate 26 cents of induced impact of 48 cents. In other words, approximately one-half of GDP is comprise of wages.

Appendix B: Survey Questionnaire

Introduction

CANARIE (Canada's Advanced Research and Innovation Network) is conducting this survey to collect evidence of its impact on Canada's research and education (R&E) community. CANARIE is a dedicated network of high-speed, fibre-optic cable that links researchers and innovators throughout Canada and around the world. CANARIE also funds programs and tools that promote the evolution of a leading-edge digital infrastructure. CANARIE receives the vast majority of its financial support from the Government of Canada. In today's fiscal environment, it is critical for CANARIE to demonstrate the benefit it generates for Canadian taxpayers, on the basis of objective evidence from its users' experiences. The data and information you provide for this survey will help CANARIE clearly communicate the benefits it generates for the Canadian R&E community, the overall economy and Canadian taxpayers. By participating in this survey and sharing your data and opinions, CANARIE will be able to continue to provide you and your institution with low-cost access to a broadband communications network configured for your R&E needs. We strongly encourage you to take the time to participate in this survey. Confidentiality: All of the information you provide to CANARIE through this survey will be held in strict confidence. Your responses will only be reported in aggregate form and without attribution. CANARIE very much appreciates the time you take to respond to these questions. The survey should require no more than 30 minutes to complete. If, at any time, you must pause the survey, you can save your answers and resume it at a later time. If you have any questions, please contact us at 613-943-5372 or harry.sharma@canarie.ca.

A. Contact information

A1. Your responses will remain anonymous and confidential. However, we would appreciate it if you provided your contact information should we need further clarification to some of your responses.

Name: [ ]

Institution/Organization: [ ]

Email: [ ]

A2. Please identify your role at the institution that you are representing for this survey.

○ Chief Information Officer (CIO) (Go to Section B)

○ Vice-President, Research (VPR) (Go to Section C)

○ Researcher (Go to Section D)

○ None of the above (Survey ends)

B. CIO Questionnaire

In order to accurately complete this survey, you will need access to detailed information on your institution's Internet usage and infrastructure, including its use of the CANARIE network.

B1. Please provide an estimate of your institution's overall annual (Internet service provider) ISP expenditures for commercial Internet bandwidth.

$/year [ ]

B2. Please estimate the percentage of your institution's total research and education (R&E) traffic (as a percentage of monthly gross traffic) that is carried by the CANARIE network or by your regional ORAN network (e.g. ORION, BCnet, RISQ, etc.).

% of R&E traffic [ ]

B3. In the next 2-5 years, how do you expect the percentage reported in Question B2 to change?

- ○ Increase significantly
- ○ Increase somewhat
- ○ No change
- ○ Decrease somewhat
- ○ Decrease significantly
- ○ Don't know

B4. Please estimate the number of users who currently have access to the CANARIE network at your institution.

[ ]

B5. Of the number of users reported in Question B4, approximately what percentage are:

Faculty researchers	
Post Doctorate students	
Graduate students	
Undergraduate students	
Industry researchers	
Other	

B6. In your opinion, how important is the CANARIE network to your institution for the following activities:

Note: National science projects and areas include: NEPTUNE, Canadian Light Source, TRIUMF, High Energy Physics, Astronomy, High Performance Computing and Compute Canada, etc.

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
To participate in National Science projects or areas	○	○	○	○	○	○
International networking connectivity	○	○	○	○	○	○
Recruitment, retention and development of highly qualified personnel (HQP) (e.g. Graduate students, Ph.D students and academic staff	○	○	○	○	○	○
General campus networking	○	○	○	○	○	○

B7. If CANARIE ceased operation on April 1, 2012, what impact would it have on the following?

	Very high impact	High impact	Moderate impact	Low impact	No impact	Not applicable
Decrease in faculty retention	○	○	○	○	○	○
Decrease in science and engineering faculty retention	○	○	○	○	○	○
Decrease in publication of research (annual number of published academic articles)	○	○	○	○	○	○
Decrease in professional networking – both national and international	○	○	○	○	○	○
Decrease in student enrolment	○	○	○	○	○	○
Decrease in attraction of graduate and Ph.D students to your institution	○	○	○	○	○	○
Decrease in attraction of leading-edge researchers to your institution	○	○	○	○	○	○

B8. How do you see your institution's usage of the CANARIE network (IP and Lightpath) changing in the next 2-5 years?

- ○ Increase significantly
- ○ Increase somewhat
- ○ No change
- ○ Decrease somewhat
- ○ Decrease significantly
- ○ Don't know

B9. How important do you believe the following network services will be for your institution in the next 2-5 years?

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
Peering (Transiting IP traffic)	○	○	○	○	○	○
IPv6	○	○	○	○	○	○
Cloud computing for research and innovation	○	○	○	○	○	○
Access Federation (e.g. EduRoam and CAF)	○	○	○	○	○	○
5G networks (combined wireless service with research and education networks)	○	○	○	○	○	○
Online collaboration including video conferencing, telepresence, document sharing, etc.	○	○	○	○	○	○
Other	○	○	○	○	○	○

B10. Does your institution make use of the CANARIE Lightpaths program?

- ○ Yes
- ○ No (Skip to B13)

B11. If you had to obtain the same level of service as a CANARIE Lightpath connection from a commercial vendor, what do you estimate the annual cost would be for the commercial connection?

$/year [ ]

B12. Please indicate how important the Lightpath connection is for the following activities:

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
Secured and dedicated end-to-end network connections	○	○	○	○	○	○
Participation in collaborative national science projects (e.g. TRIUMF, NEPTUNE, SNOLAB, SKA, Compute Canada, etc.)	○	○	○	○	○	○
Participation in national and international collaborative research projects	○	○	○	○	○	○

B13. This question refers to the federal government's four science and technology priority areas announced in the Science and Technology Strategy, released by the federal government in 2007. In which of the four Science and Technology priority areas was the CANARIE network used to conduct research at your institution?

The priorities in the Science and Technology Strategy are: (1) Environmental science and technologies, (2) Natural resources and energy, (3) Health and related life sciences technologies, and (4) Information and communications technologies.

- ☐ Environmental science and technologies
- ☐ Natural resources and energy
- ☐ Health and related life sciences and technologies
- ☐ Information and communications technologies
- ☐ None of the above

B14. What percentage of research projects at your institution include collaborative research with other institutions located within your province?

% of projects [ ]

B15. What percentage of research projects at your institution include collaborative research with institutions located in other provinces?

% of projects [ ]

B16. What percentage of research projects at your institution include collaborative research with institutions outside of Canada?

% of projects [ ]

B17. This question refers to publicly funded research at your institution. Please estimate the percentage of projects at your institution that were funded by the following agencies:

NSERC	
SSHRC	
CIHR	
CFI	
Provincial funding	
Industry Funding	
Other Funding	

B18. In your opinion, does the availability of an advanced network (i.e. CANARIE network) play a role in attracting and retaining researchers (Canadian and international) to your institution?

- ○ Critically important
- ○ Very important
- ○ Somewhat important
- ○ Not very important
- ○ Not at all important
- ○ Don't know

B19. In your opinion, how important a role has the CANARIE network played in the creation of intellectual property at your institution?

- ○ Critically important
- ○ Very important

- Somewhat important
- Not very important
- Not at all important
- Don't know

B20. What is the total number of spin-off companies that were formed between 2007 and the present, which can be attributed to research conducted at your institution?

[ ]

B21. Of the number of spin-off companies reported in Question B19, what percentage, in your opinion, involved research conducted over the CANARIE network?

- 0%
- 1% to 20%
- 21% to 40%
- 41% to 60%
- 61% to 80%
- 81% to 99%
- 100%
- Don't know

C. VPR Questionnaire

C1. What was your institution's total research income (in dollars) in the past year?

[ ]

C2. Please estimate the percentage of research income reported in C1 derived from each of the following funding sources:

NSERC [ ]

SSHRC [ ]

CIHR [ ]

CFI [ ]

Provincial funding [ ]

Industry Funding [ ]

Other Funding [ ]

C3. What is your best estimate of the percentage of your research income that supports research that uses CANARIE's network?

[ ]

C4. How important is a national advanced research and education network, CANARIE, to your institution for the following activities:

Note: National science projects and areas include: NEPTUNE, Canadian Light Source, TRIUMF, High Energy Physics, Astronomy, High Performance Computing and Compute Canada, etc.

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
To participate in National Science projects or areas	○	○	○	○	○	○
International networking connectivity	○	○	○	○	○	○
Recruitment, retention and development of highly qualified personnel (HQP) (e.g. Graduate students, Ph.D students and academic staff)	○	○	○	○	○	○
Attracting high-quality faculty, post-doctoral and doctoral students to your institution	○	○	○	○	○	○

C5. In your opinion, how important is the availability of an advanced network (i.e. CANARIE network) to the attraction and retention of Canadian researchers to your institution?

○ Critically important

○ Very important

○ Somewhat important

○ Not very important

○ Not at all important

○ Don't know

C6. In your opinion, how important is the availability of an advanced network (i.e. CANARIE network) to the attraction and retention of international researchers to your institution?

○ Critically important

○ Very important

○ Somewhat important

○ Not very important

○ Not at all important

○ Don't know

C7. Please provide the following statistics for research originating from your institution between 2007 and the present.

Total dollar value of research expenditures (i.e., research income)	
Total number of research projects	
Number of joint research projects involving remote collaboration with partners within your province	
Number of joint research projects involving remote collaboration with partners outside your province (but within Canada)	
Number of joint research projects involving remote collaboration with partners outside Canada	
Number of scientific articles (in peer-reviewed academic journals) authored by researchers at your institution	
Number of scientific articles (in peer-reviewed academic journals) co-authored by researchers at your institution with researchers at other institutions in Canada	
Number of scientific articles (in peer-reviewed academic journals) co-authored by researchers at your institution with researchers at institutions outside of Canada	
Number of patents filed by researchers at your institution	
Number of triadic patents (i.e. patents registered in the US, EU, and Japan) filed by researchers at your institution	
Number of new spin-off companies facilitated by research at your institution	
New products developed and commercialized as a result of research conducted at your institution	

C8. In your opinion, how important is the CANARIE network to achieving your institution's research objectives?

- ○ Critically important
- ○ Very important
- ○ Somewhat important
- ○ Not very important
- ○ Not at all important
- ○ Don't know

C9. In your opinion, how important were the following factors to research conducted at your institution between 2007 and the present:

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
Collaboration with researchers outside of Canada	○	○	○	○	○	○
Collaboration with researchers at institutions in other provinces	○	○	○	○	○	○
Collaboration with Network Centres of Excellence	○	○	○	○	○	○
Secure user-controlled dedicated point-to-point bandwidth	○	○	○	○	○	○
Low latency of data transmission	○	○	○	○	○	○
High bandwidth to accommodate large amounts of data generated by experiments	○	○	○	○	○	○
Bandwidth for distributed-computing research required by scientific research	○	○	○	○	○	○
Access to remote data locations (e.g.	○	○	○	○	○	○

Hubble or CERN)

Access to confidential Statistics Canada data	○	○	○	○	○	○
Immediacy of availability of dedicated bandwidth	○	○	○	○	○	○
Security and privacy of data transmission	○	○	○	○	○	○

D. Researcher Questionnaire

Note:This survey is about measuring the impacts of the CANARIE network. You may not be readily aware that you are using the CANARIE network as it is usually connected to the backend of your institution's Internet connection. So when answering the following questions, please consider the CANARIE network to be your institution's network that you access for research purposes.

D1. Which of the following scientific discipline(s) would you most closely associate with your academic research work?

☐ Particle physics

☐ Astronomy

☐ Social sciences

☐ Environmental Science

☐ Life Sciences

☐ Other, please specify: ______________________

D2. How data intensive do you consider your academic research to be?

○ Extremely data intensive (daily data transfer of 1Terra Byte (TB) or more)

○ Very data intensive (daily data transfer between 100Giga Bytes (GB) – 1TB)

○ Somewhat data intensive (daily data transfer between 10GB – 100GB)

○ Not very data intensive (daily data transfer between1GB – 10GB)

○ Not at all data intensive (daily data transfer of

○ Not applicable

D3. Please quantify each of the following that pertain to your research between 2007 and the present:

Number of joint research projects involving local partners (within your institution) ☐

Number of joint research projects involving remote collaboration with partners within your province	
Number of joint research projects involving remote collaboration with partners outside your province (but within Canada)	
Number of joint research projects involving remote collaboration with partners outside Canada	
Number of scientific articles (in peer-reviewed academic journals) authored by you	
Number of scientific articles (in peer-reviewed academic journals) co-authored by you with researchers at other institutions in Canada	
Number of scientific articles (in peer-reviewed academic journals) co-authored by you with researchers at institutions outside of Canada	
Number of patents filed in Canada due to your research	
Number of triadic patents (i.e. patents registered in the US, EU, and Japan) due to your research	
Number of new spin-off companies facilitated by your research	

D4. Please rate the following factors in terms of their importance to the completion of the academic research projects you conducted over your institution's data-communications network between 2007 and the present:

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
Collaboration with researchers outside of Canada	○	○	○	○	○	○
Collaboration with researchers at institutions in other provinces	○	○	○	○	○	○
Collaboration with Network Centres of Excellence	○	○	○	○	○	○
Secure user-controlled dedicated point-to-point bandwidth	○	○	○	○	○	○
Low latency of data transmission	○	○	○	○	○	○
High bandwidth to accommodate large amounts of data	○	○	○	○	○	○

generated by experiments						
Bandwidth for distributed-computing research required by scientific research	○	○	○	○	○	○
Access to remote data locations (e.g. Hubble or CERN)	○	○	○	○	○	○
Access to confidential Statistics Canada data	○	○	○	○	○	○
Immediacy of availability of dedicated bandwidth	○	○	○	○	○	○
Security and privacy of data transmission	○	○	○	○	○	○

D5. In the next 2-5 years, how do you anticipate your usage of the high-bandwidth network will change?

○ Increase significantly

○ Increase somewhat

○ No change

○ Decrease somewhat

○ Decrease significantly

○ Don't know

To what factors do you attribute this change?

[ ]

D6. Please estimate the cost savings you realized on an annualized basis in the following areas as a result of your use of the high-bandwidth network to conduct academic research:

	$0	$1 to $5,000	$5,001 to $10,000	10,001 to $20,000	$20,001 to $50,000	$50,000 or more	Don't know
Use of online collaboration tools to reduce travel requirements	○	○	○	○	○	○	○
Data transfers over the network (e.g. instead of using a courier to send and receive storage devices with data)	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

D7. How do you believe the importance of digital infrastructure to your academic research will change over the next five years (digital infrastructure includes components such as digital network, digital storage, computing, remote sensors, etc.)?

○ Increase significantly

○ Increase somewhat

○ No change

○ Decrease somewhat

○ Decrease significantly

○ Don't know

D8. Looking out five years from now, what are the top five digital infrastructure tools that you will want to use for your academic research (e.g. high bandwidth, cloud computing for research, use of remote sensors, wireless networking, etc.)?

1. [ ]
2. [ ]
3. [ ]
4. [ ]
5. [ ]

D9. Between 2007 and the present, did you apply for and receive funding from CANARIE for scientific research?

○ Yes (go to question D10)

○ No (skip to survey conclusion)

D10. Please indicate the CANARIE programs from which you received funding.

☐ GreenIT

☐ NEP or NEP2

☐ IEP

☐ Other, please specify: ______________________

D11. Please estimate the total amount of funding you received from each of the following CANARIE programs between 2007 and the present.

GreenIT	
NEP or NEP2	
IEP	
Other	

D12. For each of the following, please quantify the amount that pertains to your use of CANARIE funds.

Number of scientific articles (in peer-reviewed academic journals)	
Number of technical reports	
Number of invited presentations given at conferences, workshops and meetings	
Number of post-doctoral fellows trained as highly qualified personnel (HQP)	
Number of technicians trained as highly qualified personnel (HQP)	
Number of PhDs trained as highly qualified personnel (HQP)	
Number of Masters students trained as highly qualified personnel (HQP)	
Number of Undergraduates trained as highly qualified personnel (HQP)	

D13. How important was the funding support you received from CANARIE to the following activities:

	Critically important	Very important	Somewhat important	Not very important	Not at all important	Not applicable
Conducting research	○	○	○	○	○	○
Collaborating with other researchers in Canada	○	○	○	○	○	○
Collaborating with international researchers	○	○	○	○	○	○
Collaborating with Industry partners	○	○	○	○	○	○

Please provide any other comments you have on the impact that CANARIE Inc. (the organization) or the CANARIE network had on your institution, organization or own academic research between 2007 and the present.