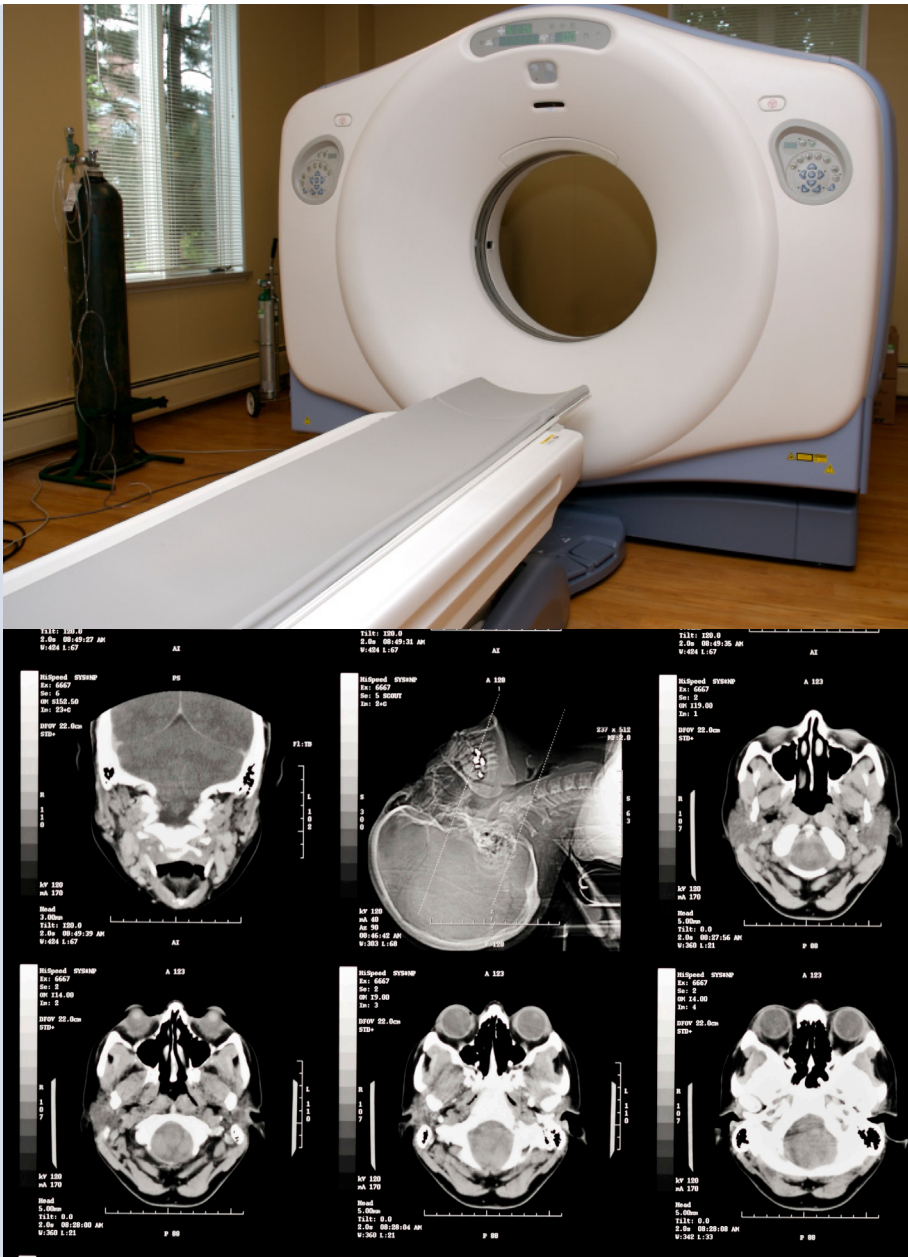
Pilot Socioeconomic Impact Analysis of CFI and CIHR Funding: Medical Imaging R&D

March 2013

RTI Project Number **0213097**

Final Technical Report



Prepared for

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

CIHR IRSC
Canadian Institutes of Health Research | Instituts de recherche en santé du Canada

Prepared by

Alan C. O'Connor
RTI International

Albert N. Link
University of North Carolina at Greensboro

RTI International
3040 Cornwallis Road
Research Triangle Park, NC, USA 27709

RTI INTERNATIONAL

RTI Project Number
0213097

Pilot Socioeconomic Impact Analysis of CFI and CIHR Funding: Medical Imaging R&D

Final Technical Report

March 2013

Prepared for

Canada Foundation for Innovation
230 Queen Street, Suite 450
Ottawa, ON K1P 5E4

and

Canadian Institutes of Health Research
160 Elgin Street, 9th Floor
Ottawa, ON K1P 0W9

Prepared by

Alan C. O'Connor
RTI International

Albert N. Link
University of North Carolina at Greensboro

RTI International
3040 Cornwallis Road
Research Triangle Park, NC, USA 27709

Contents

Figures

Tables

Acknowledgements

The project team would like to thank the many researchers and executives who contributed both their time and their expertise to this pilot study, especially those whose contributions must remain confidential. Many thanks to Frank Beier, Trevor Birmingham, Veronique Bohbot, Richard Brière, Diane Bryant, Judith Chadwick, Howard Chertkow, Louis Collins, Jason Crawford, Jeff Dixon, Cynthia Dunning, Alan Evans, Matthew Farrer, Aaron Fenster, Jennifer Fraser, Mel Goodale, David Holdsworth, Kulervo Hynynen, Thomas Jenkyn, Marita Klosek, Ting-Yim Lee, Alex McKay, Steven Miller, Adrien Owen, Bruce Pike, Natasha Raja, Carol Richardson, Michel Roberge, Raphael Ronen, Thomas Ruth, Amir Shmuel, Kevin Shoemaker, Dan Sinai, Vesna Sossi, Jon Stoessl, Keith St. Lawrence, Alexander Thiel, Terry Thompson, Anne Wallis, Sharon Wu, Martin Yaffe, and Robert Zatorre.

An advisory committee guided the research term's efforts: Jane Aubin, Chief Scientific Officer and Vice President, Research, CIHR; Robert Davidson, Vice President, Programs and Planning, CFI; Yves Gingras, Canada Research Chair and Professor, l'Université du Québec à Montréal and Scientific Director, Observatoire des sciences et des technologies (OST); Joy Johnson, Scientific Director, CIHR Institute of Gender and Health and past Chair of CIHR Subcommittee on Performance Measurement; Michel Kelly-Gagnon, President and Chief Executive Officer, Montreal Economic Institute; and Fazila Seker, Commercialization Manager, MaRS Innovation.

CFI and CIHR evaluation officers were Brandon Downs (CFI) and Laura Hillier (formerly of CIHR, now of CFI). Many other CFI, CIHR, OST, and RTI staff contributed to this project's success, especially Christoph Daigeler (CFI), Jamie Ruszkowski (formerly of CIHR), Katherine Raspopow (CIHR), Vincent Larivière (OST), Pascale Lemelin (OST), Judith Bray (CIHR), Alison Hosey (formerly of CIHR), Stéphane Pion (formerly of CIHR), and Nicola Lauzon (CIHR), Sharon Barrell (RTI), Travis Beaulieu (RTI), Sara Lawrence (RTI), Christopher Sichko (RTI), and Ryan Stevens (RTI).

Executive Summary

Medical imaging is one of Canada's research and development (R&D) strengths, and Canadian researchers have made important contributions to our understanding of human development and disease that go well beyond what would otherwise be expected of a nation of fewer than 40 million. Achieving and sustaining this level of excellence would not have been possible without the sophisticated physical research infrastructure supported by the Canada Foundation for Innovation (CFI) or Canadian Institutes of Health Research (CIHR) funding.

Given documented Canadian excellence in medical imaging and the application of medical imaging to the study of neurodegenerative and musculoskeletal diseases, to what extent has this excellence translated into socioeconomic benefits for all Canadians?

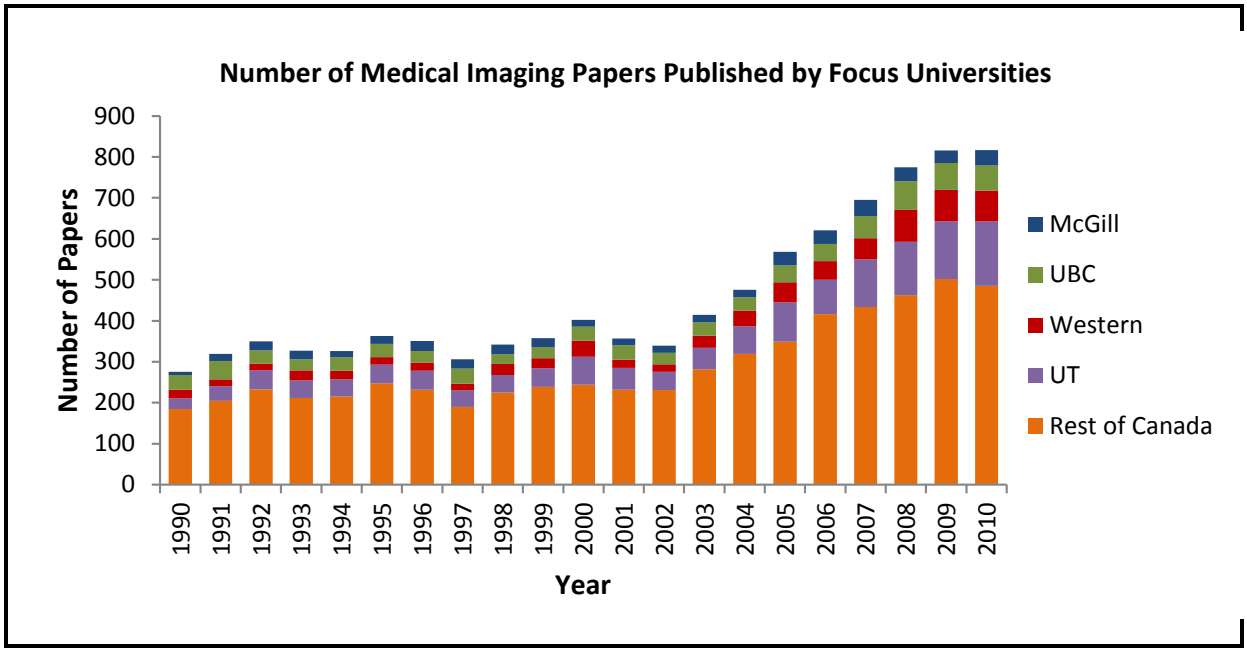
A policy commitment contained in the federal government's Science and Technology Strategy was to increase government's accountability to Canadians by "improving its ability to measure and report on the impact of S&T expenditures" (Industry Canada, 2007). Health and related life sciences and technologies is one of four priority areas that the government of Canada has committed to strengthening over time (Industry Canada, 2009).[1]

CFI and CIHR partnered in a pilot socioeconomic study using nonmarket valuation methods to begin to answer a critical question: *Given documented Canadian research excellence in medical imaging and the application of medical imaging to the*

[1] The other three are environmental science and technologies, natural resources and energy, and information and communication technologies.

study of neurodegenerative and musculoskeletal diseases, to what extent has this excellence translated into socioeconomic benefits for all Canadians?[2] **Figure ES-1** illustrates the growth in the number of papers published about the topic of medical imaging.

Figure ES-1. Growth in Scientific Publishing in Medical Imaging, 1990–2010
Scientific productivity, as measured by publications, experienced an inflection point in 2003, shortly after the creation of the Canada Foundation for Innovation in 1997 and the Canadian Institutes of Health Research in 2000. A single paper may be authored by researchers from multiple institutions and is counted for each specific institution or in the "Rest of Canada" category.



Source: Larivière and Lemelin, 2012.

ES.1 CANADA'S INVESTMENT IN MEDICAL IMAGING R&D AND RELATED HEALTH RESEARCH

Between FY1998/99 and FY2011/12, CIHR, CFI, and their provincial and university partners invested $1,033 million in medical imaging and related health research (2011$).

Between FY1998/99 and FY2011/12, CIHR, CFI, and their provincial and institutional partners invested $1,033 million in medical imaging R&D and related health research (2011$).[3] Of this sum, CFI projects amounted to $565 million, and CIHR grants and awards amounted to $468 million.

[2] The study was performed by an independent, non-profit research institute, RTI International, affiliated with Duke University, North Carolina State University, and The University of North Carolina. RTI International is a trade name of Research Triangle Institute.

[3] Excludes in-kind contributions.

Rather than evaluate the entire $1,033 million portfolio, the study focused on early medical imaging investments that were in place for long enough to have measurable outcomes. Four universities and their affiliated research hospitals and institutes participated: McGill University (McGill), The University of British Columbia (UBC), the University of Toronto (UT), and Western University (Western). Funding for these institutions was $387 million (2011$), of which $119 million was from CFI and its partners and $268 million was from CIHR.

The study's goal was to compare benefits from outcomes with the costs of that research in a systematic manner in order to estimate the public rate of return on investment.

ES.2 CT PERFUSION FOR DIAGNOSIS IN ACUTE STROKE

CT perfusion provides physicians with information about brain cells that are dead or about to die and assists physicians in their treatment decisions.

The case study for this analysis was computed tomography perfusion (CTP), an advanced imaging procedure that can be performed in just a few minutes using scanners readily available in hospitals' emergency departments. This imaging procedure uses computed tomography (CT) to measure blood flow in organs and tissues and is broadly used in acute stroke diagnosis.

It is estimated that there are more than 50,000 hospitalizations per year for strokes in Canada and approximately 300,000 people are living with the effects of a stroke. A report prepared for Public Health Agency of Canada quantified the national cost of stroke to be $3.6 billion for 2000 alone (PHAC, 2009).[4]

In a stroke situation, time is brain, and Dr. Ting-Yim Lee used CFI infrastructure and CIHR support to develop sophisticated yet easy to use tools for analyzing acute stroke.[5] GE Healthcare commercialized Dr. Lee's research, catalyzing a global sea change in how stroke victims' conditions are assessed.

CT perfusion allows the radiologist to assess blood flow in the stroke-affected part of the brain and identify brain cells that are

[4] That estimate is composed of direct healthcare costs and the indirect costs of lost productivity and premature mortality.

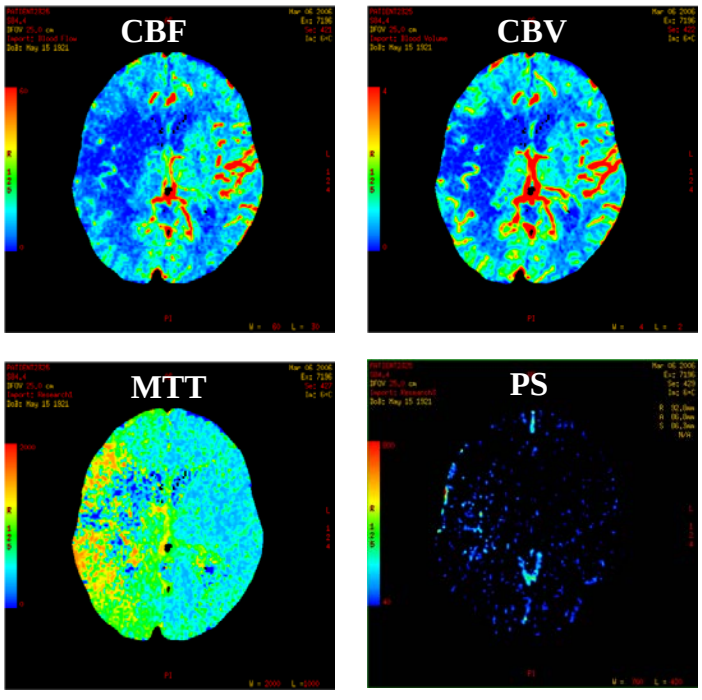
[5] Dr. Lee has multiple affiliations and positions in London, Ontario: the Lawson Health Research Institute of the London Health Sciences Centre and St. Joseph's Health Care, the Robarts Research Institute, and Western University.

at risk but could be saved. In economic studies, human health benefits are quantified in terms of quality-adjusted life years (QALYs), or the additional quantity of life an intervention offers a patient, recognizing the fact that the person has suffered an adverse health event or has an illness. Although clinical trials are still underway, a recent analysis of CT perfusion using decision analytic models determined 0.12 additional QALYs for patients, on average, because of improved diagnosis and course-of-treatment decisions (Earnshaw et al., 2012). CFI and CIHR support the accelerated introduction of CT perfusion into clinical use by at least 5 years, according to leading neuroradiologists and stroke neurologists participating in this study. **Figure ES-2** presents four components of a CT perfusion study.

The value to Canadians attributable to public support of CT perfusion is between $87 and $130 million from 2000 through 2011.

The equivalent monetary value to Canadians attributable to public support of CT perfusion is $87 million and $130 million from 2000 through 2011. When the benefits are compared with all costs, the net benefits are between $42 million and $86 million.

Figure ES-2. Example CT Perfusion Study
This figure shows the four components of a CT perfusion study: cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and permeability-surface area (PS) maps. The maps are in traditional rainbow color scale, where blue is low and red is high. High CBF and CBV are good signs. Unfortunately, the blue areas show that the patient has poor CBF and CBV. High MTT (in red) is a bad sign because it means that blood is taking too long to transit the area.



Courtesy of Dr. Richard Aviv, Sunnybrook Health Sciences Centre, Toronto, Ontario.

The resulting benefit-to-cost ratio (BCR) is between 1.5:1 and 2.3:1, meaning that for every $1 invested, $1.50 to $2.30 in value to stroke victims accrued. Such high BCR estimates reflect the inherent value of sophisticated, yet simple to use, diagnostic tools that can inform clinical care and improved health outcomes (see ***Table ES-1***).

Table ES-1. Measures of Socioeconomic Return on CT Perfusion, 2000 through 2011

Measure	Value
Net economic benefits attributable to CFI/CIHR and partners ($ million)	$42M to $86M
Additional quality-adjusted life years for Canadian stroke suffers	2,845 to 4,270
Net present value of net benefits ($ million, base year = 2000)	$16M to $39
Benefit-to-cost ratio	1.5:1 to 2.3:1
Internal rate of return	28% to 46%

CT perfusion's value to Canadians is sufficiently large to account for 7% to 10% of the national CFI, CIHR, and partner investment in medical imaging R&D and related health research since 1998.

If one were to compare the benefits for CT perfusion with

- the total imaging investment in McGill, UBC, UT, and Western through FY2011/12, the benefits from CTP alone are sufficiently large to account for 19% to 28% of the $387 million invested in imaging research at these institutions, after adjusting for the time value of money.
- the total imaging investment in all Canadian universities through FY2011/12, the benefits from CTP are sufficiently large to account for 7% to 10% of the $1,033 million investment, after adjusting for the time value of money.

The ultimate beneficiaries are stroke victims whose doctors are better equipped to diagnose their condition rapidly and recommend a course of treatment more confidently. Clearly, medical imaging R&D is a socially optimal use of public funds.

The case of CT perfusion is an excellent example of the profound effect public support of a research program can have on health outcomes. However, there are other advances in development or entering commercialization for which benefits were not quantified. Imaging research can have a time horizon of 10 years or more before commercialization and clinical application. This is the case because of the need for extensive testing, validation, and trial in animal models and humans before use in a clinical setting.

CFI projects pooled federal, provincial, and partner funding to support cutting-edge research using instrumentation that was often unique in Canada. Having secured the research infrastructure positioned the researchers well to submit competitive and successful CIHR grant applications. Other downstream effects included

- international collaborations (e.g., attraction of U.S. National Institutes of Health [NIH] funding to Canada),
- highly qualified personnel (e.g., technicians, research associates, undergraduate and graduate students, postdoctoral fellows), and
- translation of knowledge outputs into new products and services and downstream improvements to clinical care.

Without CFI and CIHR, the overall level of medical imaging research performed nationally would be lower.

1 Introduction

This study is a pilot socioeconomic impact analysis of the Canada Foundation for Innovation's (CFI's) and the Canadian Institutes of Health Research's (CIHR's) investments in Canada's university-based health research enterprise. Medical imaging is one of Canada's research and development (R&D) strengths, and Canadian researchers have made important contributions to our understanding of human development and disease that go well beyond what would otherwise be expected of a nation of fewer than 40 million. Achieving and sustaining this level of excellence would not have been possible without the sophisticated physical research infrastructure supported by CFI or CIHR health research funding.

CIHR, CFI, and partners (e.g., provincial funds, universities, foundations, corporate partners) have invested $916 million in medical imaging research between FY1998/99 and FY2011/12 (or $1,033 million [2011$] after adjusting for inflation) with the ultimate aim of improving health outcomes for all Canadians. This funding has not only supported cutting-edge research at Canadian universities, but also generated economic value for society and spurred the development of an ecosystem of start-up companies and research institutes.

According to the Organisation for Economic Co-operation and Development (OECD) (2007), "[u]nderstanding and measuring the impacts of public R&D have become a central concern of policy makers who need to evaluate the efficiency of public spending, assess its contribution to achieving social and economic objectives and legitimise public intervention by enhancing public accountability." Further, one of the policy

commitments contained in the federal government's Science and Technology Strategy was to increase government's accountability to Canadians by "improving its ability to measure and report on the impact of S&T expenditures" ((Industry Canada, 2007). This study applies methods for quantifying the return on investment of public expenditures to support government accountability for science and technology expenditures. As a socioeconomic impact analysis, this study reviews not only dollar-denominated benefits, but also health outcomes and other relevant impacts.

1.1 PILOT STUDY SCOPE

This pilot study focused on the net economic and health benefits of investments by CFI and CIHR in medical imaging technology research infrastructure and related health research.

This pilot study focused on the net economic and health benefits of investments by CFI and CIHR in medical imaging technology research infrastructure and related health research. It focused on research outcomes from these public investments at four major universities and their affiliated research hospitals and institutes (alphabetically): McGill University (McGill), The University of British Columbia (UBC), the University of Toronto (UT), and Western University (Western). The study's goal was to compare monetized benefits from one or more outcomes with the costs of that research in a systematic manner in order to estimate society's rate of return on investment.

For ease of presentation, per university nomenclature, we refer to "CFI projects" when discussing CFI-cofunded physical research infrastructure (e.g., research facilities, instrumentation, equipment) and operating support programs, but provincial, university, and other partner contributions are also included. Thus, by default, we are offering measures of return for provincial and university partners as well. Provincial funders providing matching funds for in-scope CFI projects following CFI award are listed in Table 1-1.

1.1.1 Pilot Study Objectives

The novelty of this pilot is that this is the first known application of the counterfactual evaluation method and nonmarket valuation to measure economic return in the Canadian R&D context. It is also the first study to review collectively and without assignation of attribution the roles of multiple federal, provincial, and university partners in catalyzing socioeconomic benefits. Future studies may look to

Table 1-1. Provincial Partners in CFI Medical Imaging Projects

Alberta	Ontario
Alberta Advanced Education and Technology	Government/Province of Ontario
Alberta Cancer Board	Ontario Ministry of Research and Innovation
Alberta Innovation & Science Res. Investment Program	Ontario Innovation Trust
Alberta Intellectual Infrastructure Partnership Program	Ontario Ministry Agriculture, Food, and Rural Affairs
Alberta Research Enhancement Envelope	Ontario Ministry of Economic Development and Trade
Alberta Science & Research Authority	Ontario Ministry of Research and Innovation
Government/Province of Alberta	Ontario Research & Development Challenge Fund
British Columbia	Ontario Research Fund
BC Health Research Foundation	Prince Edward Island
BC Knowledge Development Fund	Maritime Provinces Higher Education Fund
British Columbia Knowledge Development Fund	Quebec
Manitoba	Fonds de recherche du Québec−Santé
Government/Province of Manitoba	Fonds Québécois de la Recherche sur la Nature et les Technologies
Manitoba Health Research Council	Gouvernement/Province de Québec
Manitoba Innovation Fund	Ministère du Développement économique, de l'Innovation et de l'Exportation
New Brunswick	Ministère de l'Éducation, du Loisir et du Sport
New Brunswick Medical Research Fund	Ministère de la Santé et de Services sociaux
Maritime Provinces Higher Education Fund	Saskatchewan
Newfoundland and Labrador	Government/Province of Saskatchewan
Government/Province of Newfoundland	Innovation & Science Fund
Nova Scotia	Regina Qu'Appelle Health Region
Capital Health Authority	Saskatchewan Cancer Agency
Government/Province of Nova Scotia	Saskatchewan Innovation and Science Fund
Nova Scotia Research & Innovation Trust	Saskatoon Health Region
Maritime Provinces Higher Education Fund	The Saskatchewan Health Research Foundation

Source: Canada Foundation for Innovation, 2012.

this one for guidance in the approach to monetizing benefits and calculating measures of return.

The novelty of this pilot is that this is the first known application of the counterfactual evaluation method to measure economic return in the Canadian R&D context. It is also the first study to review collectively and without assignation of attribution the roles of multiple federal, provincial, and university partners in catalyzing socioeconomic benefits.

The pilot study developed and implemented strategies for comparing monetized economic benefits with costs. It not only quantified economic benefits in dollar-denominated terms, but also described and characterized the funding roles of CFI and CIHR; the mechanisms through which these institutions act; and how each supports, accelerates, and enables innovation. Thus, the study had the following objectives:

- Characterize the economic roles of CFI and CIHR, their investments, partner organizations, and research outcomes.
- Offer a broad narrative of the extent to which CFI and CIHR generated or enabled the generation of economic value for all Canadians.
- Quantify net economic benefits accruing from CIHR's, CFI's, provincial, and other partners' investments in Canada's physical research infrastructure and health research enterprise.
- Discuss implications from the findings from the study and provide recommendations to CFI and CIHR to inform future research and research-supporting initiatives.
- Identify best practices or other success factors that may be useful for future socioeconomic impact assessments moving forward.

1.1.2 Complementing CFI Outcome Measurement Studies and CIHR Impact Studies

This socioeconomic impact analysis is a complement to CFI's outcome measurement studies and CIHR's impact analyses. An important CFI evaluation protocol for universities is the outcome measurement study (OMS). OMS moved beyond the traditional approach of evaluating investment in physical research infrastructure using recipients' publications data and patenting information to one that reviewed longer-term issues of interest, including strategic research planning, research capacity, highly qualified personnel, research productivity, and measures of innovation and competitiveness (Tremblay et al., 2010).

Under OMS, rather than evaluating all CFI projects at an institution, a "theme" is established based on a comparison of a significant proportion of the dollar value of CFI investment to the institution's strategic research plan. The nexus between the research domains emphasized in the plan and CFI investments

represents candidate themes. For example, a 2008 OMS conducted at McGill included only CFI projects in a cognition and brain imaging theme. All other CFI projects at McGill were excluded from the review. The OMS theme selected will be a key thrust as identified by the university through their strategic research plan. Among candidates, it will generally be the most mature of those considered, as measured by the dollar value, age, and duration of CFI's financial support. Although the OMS approach is meaningful for evaluating CFI investments in a particular institution, it lacks the ability to capture broader impacts that go beyond the institution. These include impacts such as improved health outcomes, productivity gains, or increased R&D efficiency stemming from the commercialization or end use of knowledge and technologies rooted in university-based research.

CIHR has undertaken similar activities to advance its reporting on research impacts (Bernstein et al., 2007). Studies to date have focused on individual grants within a thematic area or specific strategic initiatives. CIHR's assessments are framed around its Impact Framework, which consists of six impact categories: knowledge, capacity, decision-making, economic, health, and health system impacts. CIHR has primarily employed a case study approach with only partial cost or economic information reported.

1.1.3 Participating "Focus" Universities

This study is a partnership between CFI and CIHR, and the initial selection criterion for OMS on which to base the pilot was that it be a health-related theme.

This study is a partnership between CFI and CIHR, in recognition of the symbiotic relationship between research facilities and research program/project support. The initial selection criterion for OMS on which to base the pilot was that it be a health-related theme. Within relevant OMS themes, OMS for "Neurosciences: Cognition and Brain Imaging" at McGill University and "Musculoskeletal Health" at Western had been completed. Further, CFI projects at these two institutions were deemed to have been in place for a sufficient time to begin to produce outcomes and evidence of monetizable economic benefits from CIHR-funded research grants that could potentially be measured.[1] After site visits to both McGill and Western, it was decided that the focus of this pilot study would

[1] CFI projects must have been completed and have been supporting CIHR-funded research grants over a multiyear period.

be on the unifying theme of medical imaging in recognition that imaging was a common research focus for both institutions.

Further, McGill and Western researchers recommended during site visits that medical imaging also include, to the extent practicable, research conducted at UBC and the Sunnybrook Research Institute (Sunnybrook) at UT. Their rationale was that these two institutions, along with their own, are generally considered to be part of the foundation of imaging research in Canada *and* received some of the first imaging-related CFI projects.

McGill and Western researchers recommended during site visits that medical imaging also include, to the extent practicable, research conducted at UBC and the Sunnybrook Research Institute (Sunnybrook) at UT.

Thus, the four so-called "focus universities" for this pilot study are

- McGill,
- UBC,
- UT, particularly Sunnybrook, and
- Western.

Each of these institutions is a parent institution with regional hospital and research institute affiliates, though the affiliates may be the grant holder. Such affiliates are included in this study, but for ease of presentation only the parent institution is named in the text. Table 1-2 lists each parent institution's affiliates.

Table 1-2. Affiliated Research Institutes and Hospitals for Focus Universities

McGill University	The University of British Columbia	University of Toronto	Western University
McGill University Health Centre (includes Montreal Children's Hospital, Montreal General Hospital, Royal Victoria Hospital, Montreal Neurological Institute and Hospital, Montreal Chest Institute)	Vancouver Coastal Health Authority (formerly Vancouver Hospital and Health Sciences Centre)	University Health Network (includes Toronto General Hospital, Toronto Western Hospital, and Princess Margaret Hospital)	London Health Sciences Centre (includes Victoria and University and Lawson Health Research Institute)
Douglas Hospital	Providence Health Care (St. Paul's Hospital)	Toronto Rehabilitation Institute	St. Joseph's Health Care, London
Sir Mortimer B. David—Jewish General Hospital	Okanagan College University	Mount Sinai Hospital—Samuel Lunenfeld Research Institute	

(continued)

Table 1-2. Affiliated Research Institutes and Hospitals for Focus Universities (continued)

McGill University	The University of British Columbia	University of Toronto	Western University
St. Mary's Hospital Centre		Holland Bloorview Kids Rehabilitation Hospital	
		St. Michael's Hospital (includes Wellesley)	
		Sunnybrook and Women's College Health Sciences Centre	
		Hospital for Sick Children	

Source: Canada Foundation for Innovation, 2012.

1.2 CFI'S AND CIHR'S ROLE IN CANADA'S MEDICAL IMAGING SECTOR

Health and related life sciences and technologies is one of four priority areas that the government of Canada, through the National Science & Technology Strategy, has committed to strengthening over time (Industry Canada, 2009).[2]

The government has targeted resources to enhance public and private research and commercialization in these domains to improve the nation's competitive advantage through innovation. As a subset of the health and life sciences focus, investments in medical imaging and related health research by CFI and CHIR align with this larger national strategy.

[2] The other three are environmental science and technologies, natural resources and energy, and information and communication technologies.

CFI and CHIR primarily play a role supporting researchers in the early stages of medical imaging R&D without which there would not be concepts to commercialize and thus enhance competitiveness and enhancements in clinical care for patients.

To understand how CFI's and CIHR's efforts fit within this national strategy, it is important to take a wider perspective on the innovation process and how it drives economic competitiveness. Innovation is well established as the foundation for medium- to long-term economic competitiveness. What is often not mentioned in competitiveness discussions is the path, which can be at times lengthy and complicated, required to foster innovation as a competitive tool.

The innovation process follows a technology development continuum that begins with basic research followed by applied research. CFI and CHIR play a role supporting researchers in these stages of medical imaging R&D without which there would not be concepts to commercialize and thus enhance competitiveness and enhancements in clinical care for patients.

1.3 IN-SCOPE MEDICAL IMAGING R&D AND HEALTH RESEARCH

A medical imaging discussion paper, prepared for Industry Canada by Dr. Andrew Sinclair in 1998, provides a starting point for characterizing Canada's imaging-related research strengths. Sinclair notes that niche sectors "centre around modality and organ/disease" (p. 50), including image generation and capture, integration tools, imaging display and fusion, image guided therapy, and image analysis.

The medical imaging definition for this study was the production, analysis, and storage of visual representations of body parts, tissues, or organs for clinical purposes. This definition included imaging of patients rather than in vitro tissues or cells. It also included research that improves imaging techniques that are directly related to patient imaging. Our objective was to analyze the socioeconomic impacts associated with funding of facilities, equipment, and instrumentation for imaging and health research programs that required that infrastructure as an input.

Research projects in scope directly increase our knowledge of human health and disease as well as have an impact on healthcare efficiency, quality, and delivery, ultimately improving quality of life and general well-being. For example, projects developed or required

- computed tomography (CT);
- positron emission tomography (PET);
- magnetic resonance imaging (MRI);
- mammography;
- ultrasonography;
- advanced image processing;
- development of biomarkers;
- comparative image analysis;
- quantitative analyses of imaging data for screening and early disease detection, directing of image-guided treatment, disease diagnosis and staging; and
- use of imaging to evaluate the effectiveness of treatment.

1.4 BIBLIOMETRIC ANALYSIS OF CANADA'S STRENGTH IN MEDICAL IMAGING R&D

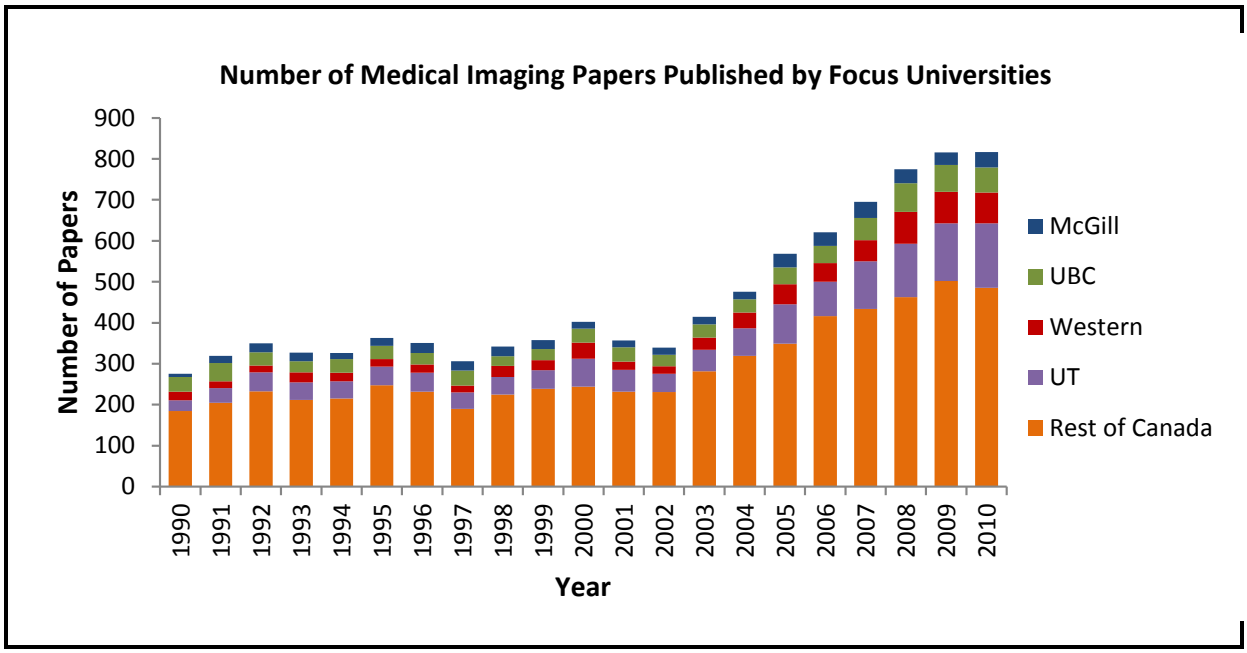
CFI and CIHR contracted with Observatoire des sciences et des technologies (OST) to provide a lens into the growth in scientific output pre- and post-CFI and CIHR creation in 1997 and 2000, respectively. Not only did the volume of papers increase over this time period, but so did the scientific quality of those papers.

Observatoire des sciences et des technologies (OST) at Université du Québec à Montréal was commissioned to provide a lens into the growth in scientific output pre- and post-CFI and CIHR creation in 1997 and 2000, respectively (Larivière and Lemelin, 2012). This was done to validate selection of medical imaging as the study theme and to review the impact of Canadian contributions to imaging-related scientific knowledge relative to others'. OST worked with experts in the medical imaging field to develop a list of scientific publications and medical imaging keywords with which to explore Thomson Reuters' Web of Science publications database.

Figure 1-1 presents some of the results of the OST analysis. Immediately evident is the increase in the number of medical imaging publications beginning in 2003—an inflection point in Canadian publication. Not only did the volume of papers increase over the 1990 to 2010 time period, but the scientific quality of those papers did also, as measured by the average of relative citations (ARC) and the average of relative impact factor (ARIF):

- ARC: a measure of the average impact of papers, which takes into account their year of publication and specialty in order for numbers to be comparable across years and specialties. A score above 1 is greater than the world average.
- ARIF: a measure of the average impact of journals in which papers are published, which takes into account the year of publication and specialty in order for numbers to be comparable across years and specialties. A score above 1 is greater than the world average.

Figure 1-1. Growth in Canadian Scientific Publishing in Medical Imaging, 1990–2010



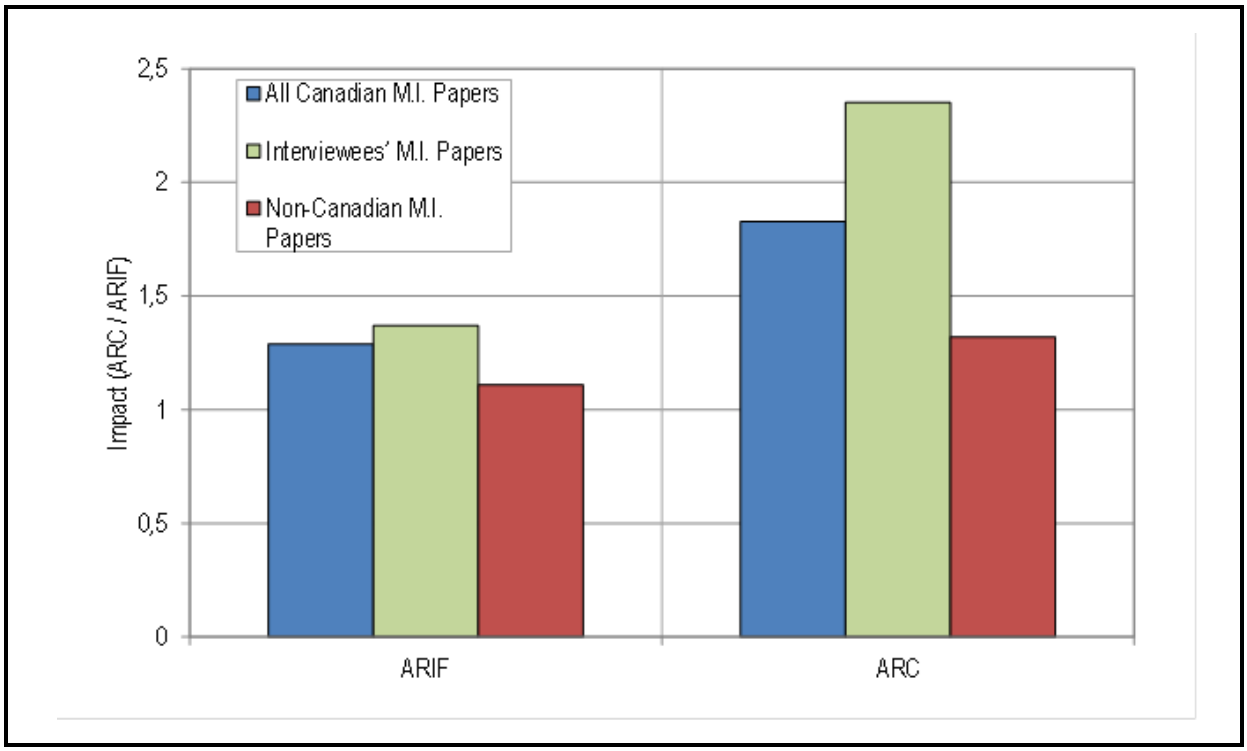
Note: A single paper may be authored by researchers from multiple institutions and counted for each institution.
Source: Larivière and Lemelin, 2012.

To what extent has excellence in medical imaging R&D and health research translated into socioeconomic benefits for all Canadians?

ARC and ARIF are indices that relate to two common questions that are frequently asked when publically funded academic research is being evaluated: (1) how useful is the information resulting from the research to other researchers and (2) how significant is the research contribution relative to some control sample.

These two indices were calculated for medical imaging researchers participating in this pilot study, all Canadian authors, and a random sample of international authors (to serve as the control sample). As shown in Figure 1-2, the scientific impact of medical imaging papers from CFI and CIHR

Figure 1-2. Scientific Impact of Canadian Papers in Medical Imaging and Related Health Research, 1990–2010



Medical imaging (M.I.). Source: Larivière and Lemelin, 2012.

projects is above world average and higher than a comparable random sample.

The results confirmed what international experts described as Canadian excellence in imaging-related research. Given this research excellence, the question of interest became: to what extent has this excellence translated into socioeconomic benefits for all Canadians?

1.5 REPORT OVERVIEW

This report is organized as follows.

- **Chapter 2** summarizes the general approach to the pilot study, reviewing key concepts in the economic evaluation of publically funded R&D. A significant portion of the study was devoted to the selection and review of appropriate economic analysis methods. This chapter reviews the application of the counterfactual evaluation method to R&D outcomes emerging from CFI-co-funded infrastructure and CIHR grant funding.

- **Chapter 3** presents CFI's, CIHR's, and partner investments in medical imaging R&D and related health research.
- **Chapter 4** is a case study of CT perfusion in acute stroke care, which is an imaging study that uses CT scanning systems to quantify blood flow in stroke-affected areas of the brain.
- **Chapter 5** presents the conclusions and lessons learned from this pilot socioeconomic impact assessment.

2 Socioeconomic Impact Analysis Methodology

There was an initial directive for the pilot study not to emphasize characteristics of the institutions performing the research or their overall research productivity, but to emphasize instead the impact of their research on Canadian society as a whole.

This chapter describes the methods used to quantify net economic benefits as well as the evolution of the pilot study from a dual focus on two health-related OMS themes to a singular focus on medical imaging. The counterfactual evaluation method was selected for quantifying economic impacts because it was developed to measure the social returns of publically funded R&D. The data to inform the analysis were collected via in-person and telephone interviews with 66 university researchers and administrators, private-sector executives, and physicians between September 2011 and February 2013.

The original period of performance for this evaluation was July 13 through December 31, 2011. However, the scope was extended twice, first to June 1, 2012, to accommodate the inclusion of UBC and UT as focus universities, and then to August 31, 2012, to afford additional calendar time for primary data collection. Final reviews were completed by February 2013.

2.1 PILOT STUDY SCOPE

At its inception the pilot study was designed to focus on reviewing research outcomes from two health-related OMS: Neurosciences: Cognition and Brain Imaging (McGill) and Musculoskeletal Health (Western). There was an initial directive for the pilot study not to emphasize characteristics of the institutions performing the research or their institutions' overall research productivity, but to emphasize instead the

socioeconomic impact of research outcomes on Canadian society as a whole. As such, a crosscutting theme was chosen.

This remainder of this section reviews the following topics in greater detail:

- definition of the medical imaging theme;
- focus university selection;
- focus research, technology, and outcome selection; and
- emphasis on net economic benefits quantification over other measures of socioeconomic return.

2.1.1 Arriving at the Medical Imaging Theme

As reviewed in the introduction to this report, we defined medical imaging as the production, analysis, and storage of visual representations of body parts, tissues, or organs, for clinical purposes. This definition included imaging of patients rather than in vitro tissues or cells. It also included research that improves imaging techniques that are directly related to patient imaging: advanced image processing, development of biomarkers, comparative image analysis, quantitative analyses of imaging data for screening and early disease detection, directing of image-guided treatment, disease diagnosis and staging, and use of imaging to evaluate the effectiveness of treatment.

The initial approach of selecting Neurosciences: Cognition and Brain Imaging (McGill) and Musculoskeletal Health (Western) investments for comparative cost basis was to remain consistent with the previous OMS. The thinking was also to reduce the level of effort of conducting the study by leveraging past work, especially the cost basis.

The idea of a single unifying theme first emerged when alternatives for assembling historical project cost data were being reviewed. It became apparent through discussions with CFI and CIHR analysts that key word searches of funded project databases would be required to assemble the time series of costs because

- projects had been awarded and performed since the original OMS were performed;
- funded project portfolios for both CFI and CIHR must be constructed using consistent decision rules and key words; and

- several researchers that were project users of CFI infrastructure were not listed as project leaders and therefore were not included in the OMS.

Refining the pilot study to medical imaging also had other advantages. Medical imaging was a common research domain across all participating institutions, and the imaging selection criterion would avoid the complicating factor of researching multiple medical topical areas in parallel. The findings from the pilot study would therefore be easier to convey to those with varying backgrounds and will not give the impression of duplicating previous OMS-related work. Another notable advantage was that it also kept the study lens focused on research domains of interest to all university partners; Western in particular preferred that its medical imaging research be a selection criterion for its projects in the study.

2.1.2 Focus University Selection

McGill and Western were asked to participate in this pilot study given the initial selection of their OMS themes; UT and UBC were added on the recommendation of interviewees during site visits to McGill and Western and following reviews of CFI- and CIHR-funded project lists in medical imaging (see Chapter 3). All four universities had received early CFI projects prior to 2002, and CIHR research funding related to those projects had been in place long enough to allow for research uptake.

All four universities had received early CFI projects, and their CIHR research using those projects as an input had been in place long enough to bear fruit.

Two site visits to McGill and Western revealed the advantages of including UT and UBC in the analysis. First, noted researchers at both McGill and Western—Aaron Fenster, Bruce Pike, Alan Evans, and David Holdsworth, among others—highlighted that along with their institutions UT and UBC are the foundational academic research centres in Canada for medical imaging that also received early CFI projects in medical imaging. Implicit in these researchers' remarks was the notion that omitting these institutions from this study might also omit significant advances in technology or health research.

Second, CFI scanned its funded project database and identified which institutions received large investments (>$500,000) in imaging-related infrastructure before 2005. The results from this exercise showed that McGill, UBC, UT, and Western (as well as their respective hospital and research institute affiliates) were the recipients that received the majority of early CFI

funding for imaging. Thus, a larger proportion of CFI's imaging-related investment would be included in the study.

Third, inclusion of UBC and UT would further the interest in making the study as "national" as possible. Although provinces other than British Columbia, Ontario, and Québec have imaging research centres, early investments in those provinces were either too recent or were far smaller in dollar value than those placed at the focus universities.

2.1.3 Focus Research Outcomes Selection

The research projects and outcomes highlighted in this study's results chapters were explored during interviews with researchers made available to CFI, CIHR, and RTI during site visits (McGill, UBC, Western) or telephone interviews (UT).[1] Research outcomes reviewed in this report were chosen based on

- interviewees' recommendations paired with their assessment of the significance of CFI infrastructure and CIHR funding in enabling the discovery or development of an outcome,
- interviewees' assessment of the commercialization status of the outcome and/or its incorporation into clinical practice,
- independent reviews by the study team, and
- recommendations from researchers' colleagues at other institutions about what outcomes should be studied based on their judgment of outcomes' scientific significance and economic impact.

[1] University administrators recommended researchers to be interviewed and provided contact information; they also scheduled interviewees to be available during predetermined pilot study team visits.

2.1.4 Emphasis on Economic Benefits Quantification over Other Impact Measures

The primary impacts of interest for this pilot study were dollar-denominated benefits and costs and the expression of these impacts in their underlying physical or time-based units.

The primary impacts of interest for this pilot study were dollar-denominated benefits and costs and the expression of these impacts in their underlying physical or time-based units. In general, socioeconomic impact studies of university-based research also place importance on measures such as job creation, highly-qualified personnel, licensing, patents, etc. These measures are important, but they are also captured by OMS and annual surveys conducted by the Association of University Technology Managers.[2] Therefore, the decision was made to rely on OMS and Association of University Technology Managers data as an indicator that economic value had been generated and that research outcomes may be embodied in products, services, or enhancements to clinical care, but to concentrate research efforts on monetizing economic impacts.

2.2 APPROACH TO NET SOCIAL BENEFITS QUANTIFICATION

The Griliches/Mansfield model for calculating economic social rates of return is generally viewed as the traditional evaluation method to use when considering the impact of a publically funded technology. Following Link and Scott (1998, 2011a, 2011b), it is, however, not the most appropriate model to use from a public accountability perspective for this study. Rather, the so-called counterfactual evaluation method is the more appropriate method, and it was implemented for this economic impact analysis.

2.2.1 Insufficiency of Social Accounting Multiplier Analyses to Study R&D Programs

The study team did not consider social accounting multiplier analysis, often referred to as input-output analysis, as a viable

[2] CFI contracted with OST at Université de Montréal (PI: Vincent Larivière) to conduct a patent and citation analysis to trace the knowledge diffusion associated with CFI/CIHR projects. The main focus was to trace the knowledge impact of individuals and assignees. A secondary focus was to review all patents in relevant classes in the U.S. Patent and Trademark Office (USPTO) database, identify Canadian inventors and assignees for medical imaging technologies, and ascertain the proportion that may be traceable to CFI/CIHR projects. This secondary focus validated the logic of including McGill, UBC, UT, and Western in the study.

In national-level analyses of R&D, the primary objective is to determine how that R&D translates into meaningful value—enhanced efficiency in resource allocation, improved productivity, and the availability of novel products and services that enhance quality of life. Social accounting analyses by definition are incapable of quantifying these benefits.

method. The objective of economic evaluations of publically funded R&D is to measure the generation of economic value—efficiency in resource allocation—through more appropriate means than social accounting multiplier analysis. Social accounting multiplier analyses, which often denominate results in employment, gross product, and labor income, for instance, assess resource reallocation or engagement within certain geographic boundaries. A new facility employs or could employ so many people, for example. These analyses are worthwhile studies at the regional level to assess effectiveness in gainfully employing existing resources or measuring the extent to which one subnational region attracts resources from another.

In national-level analyses of R&D, however, the primary objective is not to review resource reallocation but rather to determine how that R&D translates into meaningful value—enhanced efficiency in resource allocation, improved productivity, and the availability of novel products and services that enhance quality of life. Social accounting analyses by definition are incapable of quantifying these benefits.

2.2.2 Griliches/Mansfield Model for Calculating Social Rates of Return

Traditional economics-based evaluation methods frequently reference the research of Griliches (1958) and Mansfield et al. (1977). They pioneered the application of fundamental economic insight to the development of estimates of the private and social rates of return to investments in R&D. Streams of investment outlays through time—the costs—generate economic surplus through time—the benefits. Once identified and measured, these streams of costs and benefits are used to calculate rates of return, benefit-to-cost ratios (BCRs), and other related metrics.

The Griliches/Mansfield model for calculating economic social rates of return adds the public and the private investments through time to determine social investment costs, and then the stream of new economic surplus generated from those investments is the benefit. Thus, the evaluation question that can be answered from such an evaluation analysis is: *What is the social rate of return to the innovation, and how does that compare with the private rate of return?*

This is not the most appropriate question to ask from a public accountability perspective. The fact that the social rate of

return is greater than the private rate of return could validate the role of government in innovation if the private sector would not have undertaken the research; but it ignores, for example, consideration of the cost-effectiveness of the public sector undertaking the research as opposed to the private sector.

2.2.3 Counterfactual Evaluation Method for Calculating Social Rates of Return on Publically Funded R&D

A different question should be considered when publically funded investments are evaluated. Holding constant the very stream of economic surplus that the Griliches/Mansfield model seeks to measure and making no attempt to measure that stream, one should ask the counterfactual question: *What would the private sector have had to invest to achieve those benefits in the absence of the public sector's investments?*

What would the private sector have had to invest to achieve those benefits in the absence of the public sector's investments? Are the public investments a more efficient way of generating the technology than private-sector investments would have been?

The answer to this question gives the benefits of the public's investments—namely, the costs avoided by the private sector. With those benefits—obtained in practice through extensive interviews with administrators, research scientists, and those in the private sector who would have to duplicate the research in the absence of public performance—counterfactual rates of return and benefit-cost ratios can be calculated to answer the fundamental evaluation question: *Are the public investments a more efficient way of generating the technology than private-sector investments would have been?* The answer to this question is more in line with the public accountability issues and certainly is more in line with the thinking of public-sector stakeholders who may doubt the appropriateness of government's having a role in the innovation process in the first place.

Investments by CFI and CIHR in medical imaging technology and related health research fall under the rubric of publically funded R&D. The evaluation questions that were asked in this impact analysis are as follows:

- What would the private sector have had to invest to achieve the same level of benefits that were generated by public university research in medical imaging technology and related research?
- What cost and quality impacts, relative to the next best technology alternative, are associated with the end use of the outcome?

- Would the same level of benefits have been possible in the absence of CFI and CIHR research investments?
- Would the same level of benefits have accrued at the same time?

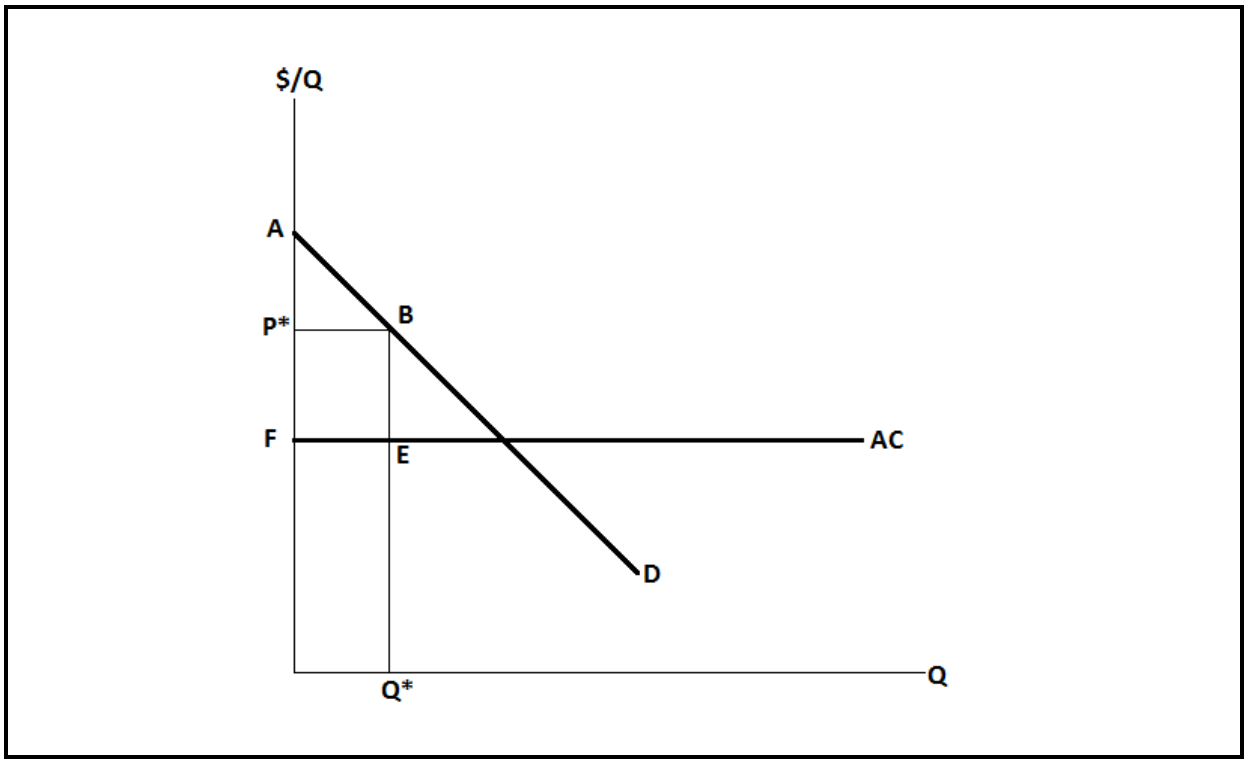
The counterfactual evaluation method can be expanded to consider gains in producer and consumer surplus associated with a firm or organization using the output associated with the publically funded technology and research.

The counterfactual evaluation method can be expanded to consider gains in producer and consumer surplus associated with a firm or organization (hereafter, firm) using the output associated with the publically funded technology and research. Although this discussion follows an example of one hypothetical firm adopting one technology, the approach is also applicable for adoption of multiple technologies and adoption by health systems and other types of organizations.

Consider Figure 2-1, which shows a firm, with average cost AC facing market demand D, that sells/licenses its differentiated product or service in amount Q* at price P* in a market with other sellers. The firm in Figure 2-1 has not benefitted from the use of the publically funded technology and research. Thus, the area defined by the triangle ABP* represents existing consumer surplus, and the rectangle P*BEF represents existing producer surplus.

Consider Figure 2-2, which shows the same firm after it has benefitted from the use of the publically funded technology and research. Market demand has increased from D to D′ because of the firm's higher quality product, and its average cost has fallen from AC to AC′ because of more efficient operations. This firm has a net gain of HGJA in total surplus because of new

Figure 2-1. Consumer and Producer Surplus

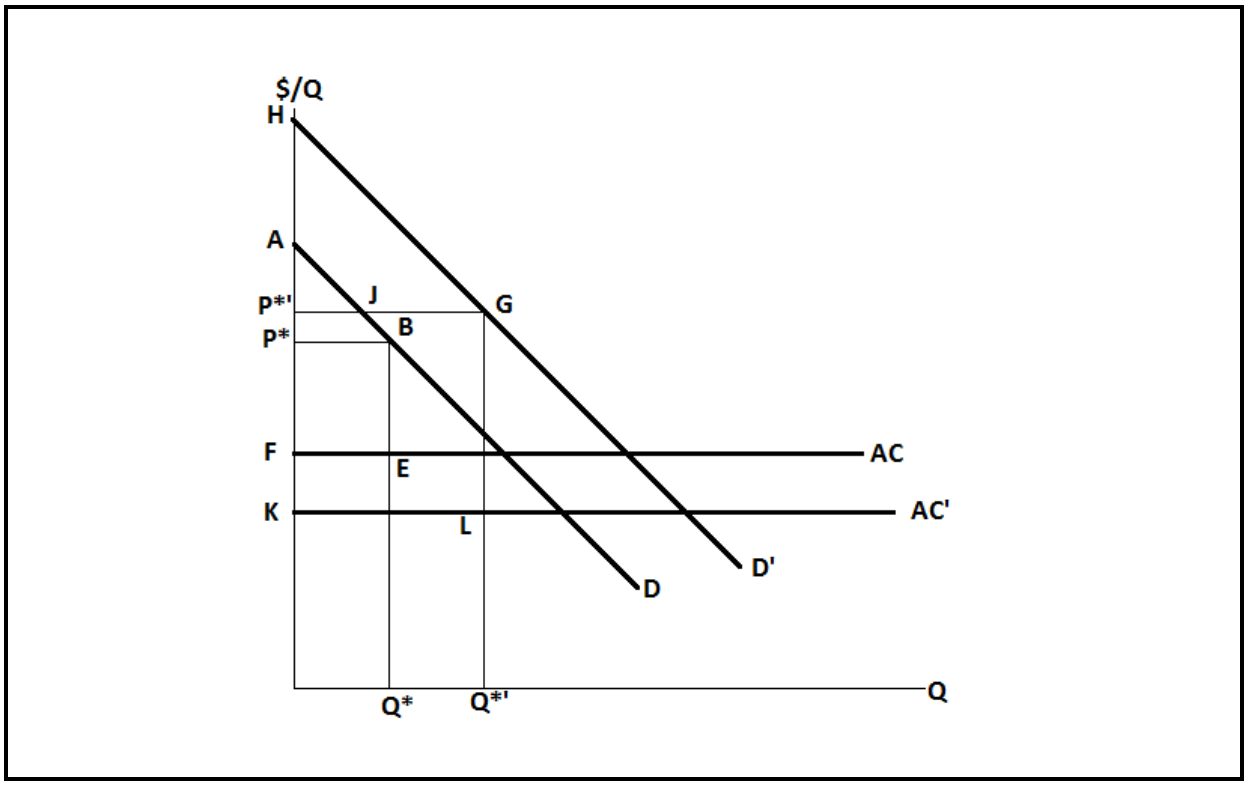


consumer surplus and a net gain of JBEFKLG in total surplus because of new producer surplus.[3, 4]

[3] The new consumer surplus is net of previously existing consumer surplus AJP*′. The new producer surplus is net of P*′JBP*, which was previously existing consumer surplus, and net of P*BEF, which was producer surplus existing before the performance excellence program. The movement from P* to P*′ reflects the movement to the new profit-maximizing equilibrium after benefiting from the publically funded, publically performed technology and research.

[4] Figure 2-2 depicts the annual effect resulting when the firm benefits from the publically funded, publically performed technology and research, but over time competition from other firms that might have implemented newer technology could be expected to erode the portion of the benefits received by the firm. Over time, other firms with competing differentiated products and efficient processes could erode the firm's profitability and hence the producer surplus. In long-run equilibrium, producer surplus may even be eliminated by price competition among the sellers/licensors of the publically funded, publically performed technology and research, although the benefits to consumers of higher quality products will increase as the prices fall and numerous competitors offer the higher quality products.

Figure 2-2. Consumer Surplus and Producer Surplus from the Adoption of Publically Funded, Publically Performed Technology and Research



Therefore, given the social costs—the public costs to generate new technology and perform research plus the cost to firms to implement that technology and research,[5] the counterfactual evaluation method estimates, in concept, the following three categories of social benefits, noting their applicability to this study:

1. the counterfactual cost savings as measured by what the private sector would have had to invest in its attempt to achieve the same level of technology and research as provided through CFI's and CIHR's R&D investments,
2. the annual net gain in consumer surplus because the technology and research were available rather than the counterfactual alternative, and

[5] This latter element of cost is often referred to as *pull cost* (Link and Scott, 2011b).

3. the annual net gain in producer surplus because the technology and research were available rather than the counterfactual alternative.

Two sets of data are needed to implement the counterfactual evaluation method: the cost associated with public research infrastructure funding and CIHR's research grants and awards, and three categories of benefits (the implementation costs avoided by the private sector, net gain in consumer surplus, and net gain in producer surplus).

In sum, the benefits from CFI's and CIHR's investments to a firm are the reduced risk and avoided costs that would have been invested in its attempt to achieve the same level of technology and research (Category 1 above) and the annual net gain in consumer surplus and producer surplus when the technology and research had not been developed through CFI's and CIHR's investments but instead are based on the counterfactual alternative developed by a firm in the absence of such investments (Categories 2 and 3 above).

It is also noteworthy that implicit in this approach are economic issues of risk and market failure. Whereas the public sector reviews potential pay-offs from R&D at the social level, a private sector firm's appetite for risk is tempered by its expectation of the extent to which it would be able to profit from the excludability and rivalry characteristics of products and services emerging from the R&D. In other words, a market failure exists because firms may not pursue socially-optimal R&D because they do not believe they will profit effectively. Publically funded, publically performed R&D, on the other hand, can mature ideas and concepts to the stage where commercial viability, from the firm's perspective, is reached.

Two sets of data are needed to implement the counterfactual evaluation method. The first set of data relates to the cost associated with CFI's research infrastructure funding and CIHR's research grants and awards, and the second set relates to the three categories of benefits described above: the implementation costs avoided by the private sector, net gain in consumer surplus, and net gain in producer surplus.

2.2.4 Implementing the Counterfactual Evaluation Method

CFI and CIHR provided annual costs from FY1998/99 through FY2011/12. An additional cost was considered: namely the cost to the private sector to implement or commercialize technology outcomes. Costs incurred by foreign entities outside of Canada were excluded.

Benefits were calculated on the basis of information collected through telephone interviews and site visits with scientists and physicians. Qualified individuals in each organization that have

implemented a technology or have internalized a research result(s) were asked a counterfactual question(s). The question(s) related to the investment that his/her organization would have had to make to achieve the same level of benefits as provided through acquiring, adopting, or licensing the medical imaging technology and research from each university from which the technology and research emerged.

If a foreign-owned firm commercializes the technology via a foreign subsidiary and pays a licence fee to a Canadian university, then the licensing revenue received by that university is counted as an economic benefit. This distinction is important because payments between parties in a national economic system are considered wealth transfers. However, a payment from a foreign party is a transfer of wealth from abroad. Therefore, it qualifies as an economic benefit. Canadian medical imaging technology can be commercialized by foreign entities that in turn introduce the offering to the Canadian market. Under such scenarios, social benefits could be lower than if a Canadian firm were to commercialize the technology and market it in Canada and abroad.

Regarding the annual net gain in consumer surplus, the firm that licenses the technology or research from one of the universities will not itself generate consumer surplus; that surplus will be generated by downstream end users that use the suite of products and services that embody the technology and research.

Regarding the annual net gain in consumer surplus, the firm that licenses the technology or research from one of the universities will not itself generate consumer surplus; that surplus will be generated by downstream end users that use the suite of products and services that embody the technology and research. The annual net gain in consumer surplus was collected via data collection with end users and monetized using nonmarket valuation strategies.

Regarding the annual net gain in producer surplus, the individuals interviewed in the upstream licensee firm may be unable to estimate the savings in scarce resources directly attributable to licensing the technology and research developed through CFI's and CIHR's investments rather than relying on the counterfactual alternative developed by a firm in the absence of such investments.

2.2.5 Evaluating a Subset of Outcomes to Quantify a Lower-Bound Portfolio Return

One method, and clearly the most conservative method, for calculating the net social benefit is to employ a portfolio

approach.[6] A portfolio approach to evaluation compares the benefits for a sample of identified private-sector benefit recipients from the population of all potential benefit recipients with the entire cost of the publically funded, publically performed research program. Or it compares the benefits of a sample of research outcomes with the entire public cost of the R&D program. A portfolio analysis approach *in effect* assumes that the subset of affected parties for which benefit information is available is the entire population of affected parties.

2.2.6 Other Valuation Approaches of Identified Benefits, including Quality-Adjusted Life Years

Some identified benefits, such as improved patient health outcomes, may be difficult to monetize using an orthodox implementation of the counterfactual evaluation method. In such cases, as in that for the CT perfusion case study presented in Chapter 4, the method's conceptual framework may be applied and complementary valuation techniques from the literature employed.

The CT perfusion case study denominated benefits in incremental quality-adjusted life years (QALYs) gained in adding CT perfusion to the stroke protocol relative to the counterfactual in which only the preexisting stroke protocol of a physical examination and unenhanced contrast CT was conducted. A QALY accounts for both quantity and quality of life resulting from healthcare interventions (Tetsch, 2002). QALYs provide the ability to assess the benefits from a variety of health-related protocols and take into account the costs incurred to improve quality of life and survival rate (Phillips, 2003).

Quantity of life, on the one hand, is measured in years of remaining life expectancy and is a relatively simple concept. Quality of life, on the other hand, is more difficult to calculate and is determined by survey methods. All of these methods, which are essentially patient surveys, operate under the same

[6] Ruegg and Jordan (2011) advocated a cluster approach for evaluating the retrospective benefit-cost studies of technologies developed from the Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE). Ruegg and Jordan argue that one can compare a cluster of technologies funded by EERE to the entire EERE budget in an effort to obtain a lower bound on a measure of net social benefits.

rating scale of 0 to 1, with a utility of 0 being the equivalent of death and 1 being the best possible state of health.

The basic idea of a QALY is simple. The amount of time spent in a state of health weighted by the utility score given to that health state. For example, 1 year of perfect health—a utility of 1—equals one QALY. Reduce the utility down to 0.5, and the result is half a QALY (Phillips, 2003).

2.3 MEASURES OF ECONOMIC RETURN AND SOCIOECONOMIC BENEFITS

For an evaluation of a public R&D-based program, two time series of data are needed. One time series is for the constant-dollar costs associated with the program; this series includes both public costs and private costs. All dollar values should be expressed in real terms, adjusted to a common year using the gross domestic product (GDP) index available from Statistics Canada (2012a). The other time series is for the constant-dollar benefits to those whose R&D is being leveraged. Several economic metrics are common in evaluations, especially when the traditional or counterfactual evaluation method is used.

2.3.1 Benefit-to-Cost Ratio

The benefit-to-cost ratio accounts for differences in the timing of cash flows, which has implications for the real value of $1 in one time period versus another.

The BCR is the ratio of the present value of all measured benefits to the present value of all measured costs. The BCR accounts for differences in the timing of cash flows, which has implications for the real value of $1 in one time period versus another.

Both benefits and costs are referenced to the initial time period, t = 0, when the project began. Letting B_t equal the benefits accrued in year *t* by firms and C_t the total costs for the project in year *t* by CFI and CIHR, then the BCR is given by

$$BCR = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \qquad (2.1)$$

where

t is the first year in which benefits or costs occur,

n is the number of years the benefits and/or costs occur, and

r is the social discount rate.

A BCR of 1 indicates a project breaks even from a financial perspective. Any project with a BCR greater than 1 is a successful project as defined in terms of monetized benefits exceeding costs.

One useful interpretation of the BCR is that the BCR value represents the dollar benefit accruing for every $1 in cost incurred over the time frame of analysis. For example, a BCR of 3.0 (alternately, 3:1) would mean that over the entire time frame $3 accrued for every $1 in cost.

Note that accrual of cost establishes the beginning of a period, or if costs are incurred over multiple years, then annual costs are placed at the beginning of each period. However, annual benefits are a value stream accruing as a consequence of the project. Because the benefit accumulates over the course of the period and the largest value of those benefits is reached at the end of the period, it is customary to assume that benefits accrue at the very end of the period. In practice, this means that benefits are discounted one additional period.

Fundamental to implementing the BCR is a value for the discount rate, r. Although the discount rate representing the opportunity cost for public funds could differ across a portfolio of public investments, the calculated metrics in this study follow the guidelines set forth by the Treasury Board Secretariat (TBS) of Canada (2007), based on analysis of Canada's economic opportunity cost of capital. Our constant/real-dollar benefit-cost analyses of proposed investments and regulations will report net present value (NPV) and other outcomes determined using a real discount rate of 8% (Jenkins and Kuo, 2007).

2.3.2 Net Present Value

In actuality the BCR calculated is the ratio of the NPV of benefits to the NPV of costs. Note that NPV allows, in principle, one means of ranking several projects ex post, provided investment sizes are similar.

The NPV of the investment in a project is calculated as the present value of benefits less the present value of costs, where the terms have the same meanings as identified for Equation (2.1). Any project that yields a positive NPV is considered economically successful. Projects that show a positive NPV when analyzed using a real social discount rate are

deemed socially advantageous. A negative NPV indicates that the costs to society outweigh the benefits, and an NPV equal to zero indicates a breakeven point.

2.3.3 Internal Rate of Return

The IRR on an investment should be interpreted as the percentage yield on an R&D project over the life of the project, often over multiple years. If the opportunity cost of funds is less than the IRR, the project was worthwhile from an ex post social perspective.

The IRR—a real rate of return in the context of constant-dollar cash flows—is the value of the discount rate, r, that equates the NPV of the stream of net benefits associated with a research project to zero. Put another way, the IRR is the value of r that sets the NPV equal to zero or results in a BCR of 1.

The IRR's value can be compared with conventional rates of return for comparable or alternative investments. Risk-free capital investments, such as government bonds, can be expected to yield rates of return under 5% in real terms, while equities seldom return more than 10% over an extended period of time. In academic studies of the diffusion of new technologies, however, real rates of return of 100% or more have been found for significant advances with broad social benefits (Tassey, 2003). It should be noted that, in cases for which costs exceed benefits, an IRR cannot be calculated.

In addition to the above quantified economic metrics that are based on traditional measures of benefits and costs, an additional category of benefits were considered qualitatively. These measures fall under the rubric of knowledge benefits, and they will be measured in terms of the intellectual output associated with public R&D (e.g., publications and patents).

2.4 PRIMARY DATA COLLECTION

Primary data were collected by telephone, during site visits, and from e-mail exchanges. Over the course of the study, 66 individuals provided information that complemented literature reviews and other data collection methods. Data collection was conducted under assurances of confidentiality for private-sector participants or assurances that names would not be associated with specific remarks for university researchers. This step was

taken to enable interviewees to speak candidly about their research activities or the impact of those activities.

Thirteen experts from Canada and the United States provided information from which the counterfactual was established in the CT perfusion case study. Representative titles included Chief of Neuroradiology; CT Product Line Director; Medical Director, CT and MR Imaging; and Professor of Radiology. Experts were qualified for interviews after we reviewed their professional expertise, research funding (if applicable), and scientific publications.

3 CFI's and CIHR's Medical Imaging R&D Funding, 1998–2011

Between FY1998/99 and FY2011/12, CFI, CIHR, and their provincial and university partners invested $1,033 million in medical imaging and related health R&D in real 2011 dollar terms (2011$).

Between FY1998/99 and FY2011/12, CFI, CIHR, and partners invested $1,033 million in medical imaging and related health research in real 2011 dollar terms (2011$).[1] Of this sum, CFI projects amounted to $565 million, and CIHR grants and awards amounted to $468 million.

Over this period, the same funding figure for McGill, UBC, UT, and Western alone was $387 million (2011$), of which $119 million was CFI and partners' funding and $268 million was CIHR funding. Please see Tables 1-1 and 1-2 for lists of provincial partners as well as focus universities and the research hospitals and institutes affiliated with them.

3.1 ASSEMBLING THE COST BASIS

The cost basis for this pilot study was composed of infrastructure and operating funds awarded for medical imaging infrastructure under CFI projects plus CIHR health research awards from FY1998/99 (CFI) and FY2000/01 (CIHR) through the close of FY2011/12. Neither CFI nor CIHR had an identifier solely for medical imaging–related projects. Therefore, to develop the cost basis, project lists were assembled by each organization using common search terms, and then the costs for projects appearing on the list were summed.

Projects were identified through French- and English-language keyword searches of CFI's and CIHR's project databases. Keyword search terms that were relevant included those related

[1] Excludes in-kind contributions.

to modalities (e.g., CT, PET, MRI) and/or advanced image processing, development of biomarkers, comparative image analysis, quantitative analyses of imaging data for screening and early disease detection, directing of image-guided treatment, disease diagnosis and staging, and use of imaging to evaluate the effectiveness of treatment. Searches were performed using PCRE-compliant[2] regular expressions with case and accent insensitivity. Fields searched included those for keywords, project abstract, and project title.

Final quality review of the combined CFI and CIHR project list assembled by keyword searches was performed by Stéphane Pion, then Assistant Director of the CIHR Institute of Cancer Research.

Searches of CFI's databases were performed by CFI's Information Systems group, and the resulting project list was reviewed by the Evaluation and Outcome Assessment group. Searches of CIHR's databases were performed by the Corporate Measurement and Data Unit, and the resulting project list was reviewed by the CIHR Institute of Cancer Research. CFI and CIHR exchanged project lists for review. Stéphane Pion, then Assistant Director of the Institute of Cancer Research, performed the final quality review of a combined CFI and CIHR project list.

3.2 CFI AND PARTNER FUNDING FOR CFI PROJECTS

What are referred to as CFI project costs in this report are the sum of CFI, provincial, university, and other partner[3] cash contributions to the total cost of projects appearing on the final CFI project list resulting from the keyword search. CFI's contribution to a project must be 40% or less of the total project value. Receipt of a CFI award triggers the release of provincial funds for the project and any other partner funding. Only cash contributions to a funded project were included in the cost basis. In-kind contributions were excluded.

CFI's project list included the annual CFI cash disbursements by fiscal year for each project. To avoid placing an information collection burden on provincial funders or universities, it was assumed that these partners' disbursements were proportional to CFI's disbursements and occurred on the same schedule. Thus, for each project, the cash contributions of partners were

[2] Perl Compatible Regular Expression
[3] Other partners may include foundations, research institutions, or corporations providing cash support.

distributed in the same manner as CFI's. The effect of the assumption is indeterminate. If the disbursements actually occurred earlier, the costs would be slightly understated. If they occurred later, they would be slightly overstated.

Although the award of a CFI project triggered the award of matching funds from provincial and partner sources, this study makes no claim about the relative effectiveness of one funder's dollar over another's. All parties—CFI, provinces, and partners—share attribution equally.

Although the award of a CFI project triggered the award of matching funds, this study makes no claim about the relative effectiveness of one funder's dollar over another's. In other words, all parties—CFI, provinces, universities, and other partners—share attribution equally.

CFI project costs for 315 medical imaging–related projects totaled $491.80 million between FY1998/99 and FY2011/12, consisting of

- $195.25 million in CFI cash disbursements (40%) and
- $296.56 million in province and partner disbursements (60%) (e.g., university, foundation, corporate partner) (see Table 3-1).

Table 3-1. CFI, Province, University, and Partner Cash Disbursements for Medical Imaging Infrastructure Projects, FY1998/99–2011/12

Fiscal Year	CFI ($ million)	Provinces, Universities, and Other Partners ($ million)	Total ($ million)
1998/99	0.78	1.22	2.00
1999/00	6.31	6.10	12.41
2000/01	16.95	25.08	42.02
2001/02	27.33	40.13	67.47
2002/03	5.35	10.48	15.83
2003/04	16.56	20.73	37.29
2004/05	6.16	7.55	13.71
2005/06	10.26	16.74	27.01
2006/07	18.35	26.83	45.18
2007/08	28.51	41.78	70.29
2008/09	14.86	21.49	36.34
2009/10	16.38	23.13	39.51
2010/11	16.05	35.67	51.73
2011/12	11.40	19.63	31.02
Total	195.25	296.56	491.80

Note: Data in this table are in nominal terms. Source: Canada Foundation for Innovation, 2012.

Costs associated with the four focus universities totaled $101.66 million (21% of total funding) (Table 3-2):

Before adjusting for inflation, CFI project costs for 315 medical imaging–related projects totaled $491.80 million, of which focus universities accounted for $101.66 million (21%).

- $38.52 million at McGill
- $26.92 million at UBC
- $16.15 million at UT
- $20.08 million at Western

Note that for some years disbursements from CFI to a university were negative. In FY2002/03, a delay in the development and construction of the McConnell Brain Imaging Centre at McGill prompted a return of funds from McGill to CFI for incorporation into CFI's financial investment portfolio. Funds were redistributed to McGill in subsequent years. UBC experienced a similar scenario.

Table 3-2. CFI, Province, and Partner Cash Disbursements for Medical Imaging Infrastructure Projects, Focus Universities, FY1998/99–2011/12

Fiscal Year	McGill University ($ million)	The University of British Columbia ($ million)	University of Toronto ($ million)	Western University ($ million)	Total, Focus Universities ($ million)	Percentage of Canada
1998/99	0.63			0.22	0.85	42%
1999/00	0.19	0.28			0.47	4%
2000/01	0.29		0.30	0.33	0.91	2%
2001/02	29.29	3.77	0.56	5.51	39.12	58%
2002/03	(18.98)	8.37	0.22	3.05	(7.35)	
2003/04	0.40	7.78	0.35	0.75	9.28	25%
2004/05	4.41	(2.55)	0.47	0.23	2.56	19%
2005/06	5.46	3.65	2.20	3.22	14.53	54%
2006/07	3.46	2.24	0.25	1.89	7.84	17%
2007/08	0.89	1.50	0.63	0.60	3.62	5%
2008/09	0.88	0.22	1.67	1.13	3.90	11%
2009/10	9.48	0.02	1.22	1.27	11.98	30%
2010/11	1.77	0.46	7.97	0.14	10.34	20%
2011/12	0.37	1.16	0.32	1.76	3.60	12%
Total	38.52	26.92	16.15	20.08	101.66	21%

Note: Data in this table are in nominal terms. Source: Canada Foundation for Innovation, 2012.

3.3 CIHR HEALTH RESEARCH FUNDING

Before adjusting for inflation, CIHR funding for 1,622 imaging–related health research funding amounted to $423.77 million, of which $243.06 million was granted to focus universities (57%).

Total CIHR funding for 1,622 medical imaging–related health research grants and awards across Canada amounted to $423.77 million between FY2000/01 and FY2011/12, of which $243.06 million was granted to focus universities (see Table 3-3). The breakdown between the four focus universities was

- $59.54 million at McGill,
- $42.94 million at UBC,
- $83.89 million at UT, and
- $56.69 million at Western.

The four focus institutions are consistently awarded through competitive processes 55% to 60% of CIHR research dollars in the area of medical imaging, when our project-specific medical imaging definition is applied. Funding data prior to 2000 from CIHR's predecessor, the Medical Research Council, were not available.

Table 3-3. CIHR Health Research Funding Related to Medical Imaging, FY2000/01–2011/12

Fiscal Year	Canada ($ million)	McGill University ($ million)	The University of British Columbia ($ million)	University of Toronto ($ million)	Western University ($ million)	Total, Focus Universities ($ million)	Percentage of Canada
2000/01	7.77	1.07	0.76	1.73	1.87	5.44	70%
2001/02	15.02	2.02	0.85	3.57	2.51	8.94	60%
2002/03	20.18	3.51	1.34	4.63	2.59	12.06	60%
2003/04	26.12	4.88	1.74	5.12	2.81	14.56	56%
2004/05	28.68	4.58	1.89	5.48	3.12	15.07	53%
2005/06	33.45	5.51	2.80	7.77	3.67	19.75	59%
2006/07	37.14	6.69	4.56	7.21	3.95	22.40	60%
2007/08	41.15	6.12	4.58	8.30	3.93	22.94	56%
2008/09	46.74	5.87	5.43	10.11	4.71	26.12	56%
2009/10	48.25	6.19	6.12	9.82	5.23	27.38	57%
2010/11	57.97	6.29	6.98	9.98	10.24	33.49	58%
2011/12	61.31	6.80	5.90	10.16	12.05	34.91	57%
Total	423.77	59.54	42.94	83.89	56.69	243.06	57%

Note: Data in this table are in nominal terms. Source: Canadian Institutes of Health Research, 2012.

3.4 SUMMARY CFI, CIHR, AND PARTNER FUNDING IN NOMINAL AND REAL TERMS

Combined CFI project and CIHR funding amounted to $915.6 million (nominal terms) between FY1998/99 and FY2011/12, about 54% of which was for CFI projects and 46% was for CIHR grants and awards. The combined investment at the four focus universities was $344.7 million (38% of Canada total) (see Table 3-4).

In real terms (2011$), the combined CFI project and CIHR funding of medical imaging–related infrastructure and research projects amounted to $1,032.92 million, of which $387.27 million was awarded to McGill, UBC, UT, and Western, including their affiliated institutes and hospitals.

By convention, public investments in R&D are adjusted to account for the time value of money using a chained GDP index (Ruegg and Jordan, 2011). When converting from nominal to real terms referenced to 2011, all dollar values are denoted as 2011$. The conversion from nominal to real terms relies on data from Statistics Canada. Table 3-5 includes the GDP index used to adjust the cost data in Table 3-4 (and all other nominal monetary values in this analysis) to the 2011$ values presented in Table 3-6.

Because fiscal years (April to March) and calendar years (January to December) do not align, to simplify calculations the main calendar year into which the fiscal year falls (from April to December) was chosen as the index for the entire fiscal year. For example, costs in FY1998/99 were inflated to 2011 using the corresponding index value for 1998. In addition, to simplify presentation of costs (calculated by fiscal year) and benefits (calculated by calendar year), costs were assigned to each fiscal year's primary calendar year. All of FY1998/99's costs were placed in 1998, for example.

Table 3-4. Combined CFI Project and CIHR Funding Data, FY1998/99–2011/12

	Canada			Focus Universities			
Fiscal Year	CFI Project ($ million)	CIHR ($ million)	Total ($ million)	CFI Project ($ million)	CIHR ($ million)	Total ($ million)	Percentage of Canada
1998/99	2.00	-	2.00	0.85	-	0.85	42%
1999/00	12.41	-	12.41	0.47	-	0.47	4%
2000/01	42.02	7.77	49.79	0.91	5.44	6.35	13%
2001/02	67.47	15.02	82.49	39.12	8.94	48.07	58%
2002/03	15.83	20.18	36.01	(7.35)	12.06	4.71	13%
2003/04	37.29	26.12	63.41	9.28	14.56	23.83	38%
2004/05	13.71	28.68	42.39	2.56	15.07	17.63	42%
2005/06	27.01	33.45	60.46	14.53	19.75	34.28	57%
2006/07	45.18	37.14	82.32	7.84	22.40	30.24	37%
2007/08	70.29	41.15	111.44	3.62	22.94	26.55	24%
2008/09	36.34	46.74	83.08	3.90	26.12	30.03	36%
2009/10	39.51	48.25	87.75	11.98	27.38	39.36	45%
2010/11	51.73	57.97	109.69	10.34	33.49	43.83	40%
2011/12	31.02	61.31	92.33	3.60	34.91	38.52	42%
Total	491.80	423.77	915.58	101.66	243.06	344.72	38%

Note: Data in this table are in nominal terms. CFI project amounts include CFI and partner funding. Source: Canada Foundation for Innovation, 2012, and Canadian Institutes of Health Research, 2012.

Table 3-5. GDP Index for Adjusting Monetary Values from Nominal to Real Terms, FY1998/99–2011/12

Fiscal Year	Calendar Year	Index
1998/99	1998	0.7279
1999/00	1999	0.7405
2000/01	2000	0.7713
2001/02	2001	0.7800
2002/03	2002	0.7886
2003/04	2003	0.8147
2004/05	2004	0.8407
2005/06	2005	0.8683
2006/07	2006	0.8912
2007/08	2007	0.9196
2008/09	2008	0.9574
2009/10	2009	0.9393
2010/11	2010	0.9669
2011/12	2011	1.0000

Source: Statistics Canada, 2012a.

Table 3-6. Combined CFI Project and CIHR Funding (2011$), Canada and Focus Universities

		Canada			Focus Universities		
Fiscal Year	Calendar Year*	CFI Project ($ million)	CIHR ($ million)	Total ($ million)	CFI Project ($ million)	CIHR ($ million)	Total ($ million)
1998/99	1998	2.75	-	2.75	1.17	-	1.17
1999/00	1999	16.76	-	16.76	0.64	-	0.64
2000/01	2000	54.48	10.07	64.56	1.18	7.06	8.23
2001/02	2001	86.50	19.26	105.76	50.16	11.47	61.62
2002/03	2002	20.07	25.59	45.66	(9.31)	15.29	5.98
2003/04	2003	45.77	32.06	77.84	11.39	17.87	29.25
2004/05	2004	16.31	34.11	50.42	3.04	17.92	20.97
2005/06	2005	31.10	38.53	69.63	16.73	22.74	39.48
2006/07	2006	50.69	41.68	92.37	8.80	25.14	33.94
2007/08	2007	76.43	44.75	121.19	3.94	24.94	28.88
2008/09	2008	37.96	48.82	86.78	4.07	27.29	31.36
2009/10	2009	42.06	51.36	93.43	12.76	29.15	41.90
2010/11	2010	53.50	59.95	113.45	10.69	34.64	45.33
2011/12	2011	31.02	61.31	92.33	3.60	34.91	38.52
Total		565.42	467.49	1,032.92	118.85	268.42	387.27

Note: Costs by fiscal year were assigned to their primary calendar year to simplify presentation of benefits estimated in later chapters. CFI project amounts include CFI and partner funding. Source: Canada Foundation for Innovation, 2012 and Canadian Institutes of Health Research, 2012.

In real terms (2011$), the combined CFI project and CIHR funding of medical imaging–related infrastructure and research projects amounted to $1,032.92 million, of which $387.27 million was distributed to McGill, UBC, UT, and Western.

4 Case Study: CT Perfusion

The case study for the pilot is that of CT perfusion (CTP), an imaging study that uses computed tomography (CT) to measure blood flow in organs and tissues. CTP is increasingly used in managing moderate to severe acute ischemic stroke. Analyses of available clinical data have strongly suggested improvements in health outcomes for patients having received CTP studies. Those outcome data in combination with estimated prevalence of CTP usage permitted estimation of the socioeconomic value of CTP in dollar terms using nonmarket valuation methods.

A CTP study is performed to measure blood flow in the stroke-affected area of the brain. It can also be performed to measure blood flow in the heart, the liver, or tumours, for example (Hoeffer et al., 2004).

According to neuroradiologists and stroke neurologists participating in this study, CIHR, CFI, and partner support accelerated the introduction of CTP into clinical use by at least 5 years. When the benefits of this acceleration are compared to the costs, the benefit-to-cost ratio is estimated to be 1.5:1 to 2.3:1. This is a lower-bound estimate because all known public costs related to CTP, including a substantial amount for non-CTP research, were compared with only CTP-related benefits. The estimate is doubly conservative because benefits beyond 2011 were not estimated in this retrospective analysis.

4.1 EMERGENCE OF CT PERFUSION STUDIES FOR ACUTE STROKE MANAGEMENT

There are three broad categories of stroke: ischemic (related to blood clots), hemorrhagic (bleeding), and transient ischemic attack (TIA). In this case study, the condition of interest is acute ischemic stroke, for which CTP is most commonly used.

CTP can also be used to measure blood flow in other conditions of the brain such as tumours or vascular malformations and in other organs such as the heart or the liver (Hoeffer et al., 2004).

Put simply, a stroke occurs when blood flow in the brain is interrupted, usually from a clot, which causes brain cells to rapidly die off because of an inadequate supply of oxygen and nutrients. Depending on which part of the brain is affected and the severity of the stroke, the patient may recover, suffer paralysis or other impairment, or even die.

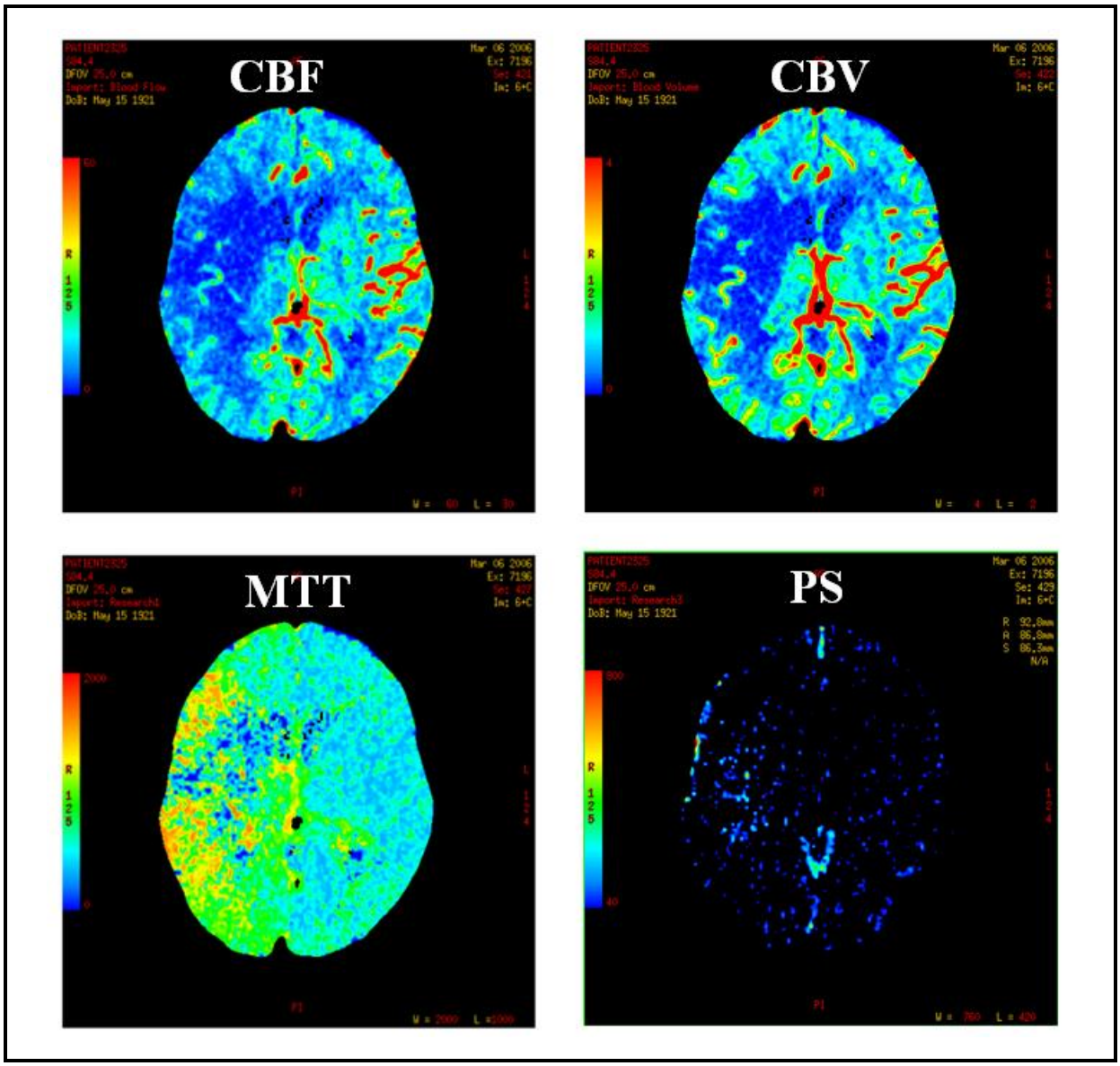
CTP can be used immediately following the unenhanced CT to provide the treating physician with additional information about the area of dead brain cells (infarct), the surrounding area of brain cells at risk but potentially salvageable (penumbra), and quantitative measures of blood flow in the area.

After a physical exam, the first imaging study used to assess stroke in an acute setting (e.g., hospital emergency room) is an unenhanced CT to rule out brain hemorrhage (Canadian Stroke Network, 2011). CTP can be used immediately following the unenhanced CT to provide the treating physician with additional information about the area of dead brain cells (infarct), the surrounding area of brain cells at risk but potentially salvageable (penumbra), and quantitative measures of blood flow in the area. The most commonly used perfusion measures are (1) cerebral blood flow (CBF), (2) cerebral blood volume (CBV), and (3) mean transit time (MTT).

Figure 4-1 presents an example of a CTP study, courtesy of Dr. Richard Aviv of the Sunnybrook Health Sciences Centre in Toronto. The four images show CBF, CBV, MTT, and permeability-surface area (PS) maps. The images are in traditional rainbow color scale, where blue is low and red is high. The blue areas on CBF and CBV indicate that there is decreased blood flow and volume while the high MTT (in red) is indicating that the blood is taking too long to transit the area.

This patient presented less than 6 hours from stroke onset. There was a large ischemic defect in the right middle cerebral artery territory with matched decrease in CBF and CBV, indicating an infarct already at admission. In layman's terms, the stroke affected the right half of the brain where motor functions of the left-hand side of the body are controlled. (Note: the patient's right side of the brain is on the left side of the images.) The PS map shows petechial blood-brain barrier disturbances that eventually led to hemorrhage in this patient 5 days later.

Figure 4-1. Example CT Perfusion Study
This figure shows the four components of a CT perfusion study: cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT). The blue areas on CBF and CBV indicate that there is decreased blood flow and volume while the high MTT (in red) is indicating that the blood is taking too long to transit the area.



Courtesy of Dr. Richard Aviv, Sunnybrook Health Sciences Centre, Toronto, Ontario.

CTP may help the physician more conclusively assess the patient's condition, including whether the patient may be a candidate for thrombolysis (Hopyan et al., 2010). Thrombolysis is the use of pharmaceuticals (namely, tissue plasminogen activator [tPA]) delivered intravenously to break up the blood clot that is the source of the stroke. tPA is commonly used in instances of acute ischemic stroke but prescribing it is not

GE Healthcare, one of four major manufacturers of CT scanner systems, released "CT Perfusion" in 2000. The algorithms and protocol in this software package for quantifying CBF, CBV, and MTT were developed by Ting-Yim Lee.

without risk. Because thrombolysis acts by thinning the blood, there is a risk of hemorrhage.

CBF, CBV, and MTT are quantified using software embedded with algorithms that analyze images captured at regular intervals by the CT scanner. While undergoing the CT scan, the patient receives a contrast agent intravenously, and the raw radiographic data are transmitted from the scanner to the software, which then calculates measures. CTP adds between 5 and 10 minutes to the imaging time (Wintermark, 2002a; Miller et al., 2008).

The first commercially available software for CTP was released in 2000 by GE Healthcare, one of four major manufacturers of CT scanner systems. The algorithms and protocol in this software package for quantifying CBF, CBV, and MTT were developed by Ting-Yim Lee. Lee has multiple affiliations and positions in London, Ontario: the Lawson Health Research Institute of the London Health Sciences Centre and St. Joseph's Health Care, the Robarts Research Institute, and Western University.

Lee's research into CTP was seeded in 1995 with funding from the Medical Research Council (MRC),[1] which preceded CIHR, and later greatly expanded under CFI projects and CIHR grants. GE Healthcare currently holds an exclusive license to the algorithms and software implementation of the CTP method developed by Lee.

CTP progressed rapidly from discussion and validation in the literature in the late 1990s and the 2000s to a tool that is being used in Canadian hospitals.

CTP progressed rapidly from discussion and validation in the literature in the late 1990s and the 2000s to a tool that is being used in Canadian hospitals to assess the condition of patients, particularly those experiencing moderate to severe acute ischemic stroke.

The concept of using imaging scans to study cerebral blood flow was first proposed by Axel in 1980, but the concept was impractical at the time given technical limitations of then-available imaging systems (Axel, 1980). In subsequent decades, sophisticated CT scanning systems and the associated computing infrastructure needed to process images eliminated

[1] Lee also received support from the Heart and Stroke Foundation of Ontario and the Canadian Anesthesia Society that contributed, in part, to research related to CTP.

In an acute stroke situation, when every moment counts, the ubiquity, speed, and availability of CT erodes MR's advantages (Parsons, 2008).

those limitations, and neuroradiologists began studying the appropriateness and diagnostic accuracy of CTP. Perfusion measurements can also be done by magnetic resonance (MR), which will provide greater detail as well as supplemental information about the patient's condition than could CT. However, MR systems are not as ubiquitous as CT systems and MR studies would take 20 to 40 minutes more to conduct. In an acute stroke situation, when every moment counts, the ubiquity, speed, and ease of scheduling of CT erode MR's advantages (Parsons, 2008).

A seminal paper by Wintermark et al. (2002a) validated the accuracy of CTP in quantifying CBF, predicting final infarct size, and evaluating the clinical prognosis for acute stroke patients in an emergency department setting. This paper was subsequently followed by other studies that compared CTP with MR that concluded that CT correlated closely with MR in quantification of perfusion (Wintermark et al., 2002b; Eastwood et al., 2003). The software used in these studies was CT Perfusion, which had received U.S. Food and Drug Administration approval in 2000.

Papers reviewing CTP's clinical advantages, role in supporting acute ischemic stroke care, and recommended protocols are prevalent in the scientific literature. Shetty and Lev (2005) noted that CTP's speed, simplicity, and accuracy would have implications for stroke patients worldwide.

In the years following CTP's clinical validation, papers reviewing CTP's clinical advantages, role in supporting acute stroke care, and recommended protocols entered the scientific literature. In addition to 11 trials associated with stroke treatment, there are trials for other conditions underway:

- Perfusion CT Imaging to Evaluation Treatment Response in Ovarian Cancer Patients Participating in GOG-0262 (Sponsored by the U.S. National Cancer Institute/American College of Radiology Imaging Network)
- Multi-institution Study of DCE CT Imaging Biomarkers of Tumor Microvasculature in Metastatic Renal Cell Carcinoma Treated with Sunitinib—Reproducibility and Response Prediction (Sponsored by Ontario Institute of Cancer, High Impact Clinical Trial Program)
- CIHR Medical Imaging Trial Network of Canada (MITNEC) project to measure perfusion in the heart of CAD patients and compare the measurement with clinical "gold" standards

Hoeffner et al. (2004) published a review of CTP as a technique and noted its clinical potential not only for stroke but also for vasospasm and tumors. Shetty and Lev (2005) noted that CTP's speed, simplicity, and accuracy would have implications

for stroke patients worldwide. Other clinicians offered reviews, recommendations, and assessments of its clinical utility (e.g., Srinivasan et al. [2006], de Lucas et al. [2008], Parsons [2008], Lui et al. [2010]), including from the nursing perspective (Summers and Malloy, 2011). In a study supported by CIHR, Hopyan et al. (2010) documented that a stroke protocol that includes CTP increases diagnostic performance.

CTP software is currently available from GE Healthcare, Siemens, Philips, and Toshiba, all of which market CT scanning systems globally.

4.2 CFI- AND CIHR-SUPPORTED CT PERFUSION RESEARCH

CFI's and CIHR's funding was fundamental to Dr. Lee's research program and provided the needed infrastructure and operating grants that supported the development of algorithms that GE Healthcare commercialized as "CT Perfusion."

CTP algorithm and software development has been a career focus for Ting-Yim Lee. He spent 8 years as a hospital physicist before pursuing a career in research. As a consequence of that experience, Dr. Lee told us during interviews that he had a distinct interest in tools that had direct clinical application. The underlying motivation for investigating CT's application in perfusion imaging was to convert imaging data from qualitative information into objective indicators using readily available scanners and that did not require specially trained personnel to interpret.

Funding from CIHR (and its predecessor, MRC) and the CFI was fundamental to Lee's research program and provided the needed infrastructure and operating grants that supported the development of algorithms that GE Healthcare commercialized as "CT Perfusion" in 2000 (Version 1), 2002 (Version 2), 2003 (Version 3), and 2008 (Version 4).

4.2.1 CFI Project Funding

Two CFI projects provided the necessary CT instrumentation (Table 4-1):

- CFI Project 317, London Imaging Research, led by Frank Prato and awarded in 1999 with disbursements beginning in 2000
- CFI Project 11358, Biomedical Multimodality Hybrid Imaging, led by Frank Prato and awarded in 2006 with disbursements beginning in 2007

Table 4-1. CFI Project Funding, FY2000/01—FY2011/12

Fiscal Year	CFI 317, London Imaging Research		CFI 11358, Biomedical Multimodality Hybrid Imaging		Total (Current)		Total (2011$)	
	Full Project Costs	CTP only Costs	Full Project Costs	CTP only Costs	Full Project Costs	CTP only Costs	Full Project Costs	CTP only Costs
1998/99								
1999/00								
2000/01	6,090,028	1,930,242			6,090,028	1,930,242	7,895,865	2,502,604
2001/02	1,397,909	443,069			1,397,909	443,069	1,792,264	568,060
2002/03	1,232,364	390,599			1,232,364	390,599	1,562,637	495,280
2003/04					—			
2004/05					—			
2005/06					—			
2006/07					—			
2007/08			11,561,761	3,095,280	11,561,761	3,095,280	12,573,168	3,366,051
2008/09			8,587,572		8,587,572		8,969,556	
2009/10			1,377,739		1,377,739		1,466,812	
2010/11			1,666,580		1,666,580		1,723,673	
2011/12					—			
Total	8,720,301	2,763,910	23,193,652	3,095,280	31,913,953	5,859,190	35,983,974	6,931,994

Source: Canada Foundation for Innovation, 2012.

Project 317 was for MR, electroencephalography (EEG), and CT instrumentation valued at $8,720,301 (cash only, nominal terms), of which CFI contributed $2,864,000 and the province and university contributed $5,853,601. The project supported multiple imaging research initiatives; the CT component (317-SP3) was distinct in the budget and accounted for $2,763,910. The funds allowed Dr. Lee to upgrade CT scanning capabilities at St. Joseph's Hospital and to increase access to the scanning facilities for software development and research.

Project 11358 was a large-scale capital facilities development and instrumentation investment program valued at $23,193,652. As before, the CT component was distinct in the budget and accounted for $3,095,280 to support the acquisition of a CT scanner with a 4-cm wide detector.

After adjustment to real terms using real GDP (chained),

- the CT-specific CFI project cost for CTP research only amounts to $6,931,994 (2011$)
- the full project costs amounts to $35,983,974 (2011$)

4.2.2 CIHR Research Funding for CT Perfusion

Lee's operating support for CTP research was rooted in projects funded by the Heart and Stroke Foundation of Ontario (HSFO) but began in earnest with MRC funding in 1995 and continued by CIHR from 2000 to the present.[1] MRC and CIHR operating support covered the core application area of acute stroke and development for emerging clinical applications for myocardial infarction (heart attack) and oncology (cancerous tumours).

CIHR has funded CTP R&D continuously since 2000 through six awards (Table 4-2):

- CIHR 61010, Multi-slice CT and MR CBF Perfusion Mapping in Thrombolytic Treatment of Stroke
- CIHR 64574, CT Cardiac Perfusion Imaging
- CIHR 98017, Development of New PET/CT Techniques for Imaging Tumour Hypoxia
- CIHR 146177, Perfusion and Lipid Imaging with a Liver Specific CT Contrast Agent to Detect Progression of Cirrhosis to Hepatocellular Carcinoma

[1] In fact, Dr. Lee submitted multiple applications to the MRC to have CTP research funded before finally being granted funding in 1995.

Table 4-2. CIHR Funding Supporting CTP Research and Total CFI and CIHR Funding, FY2000/01—FY2011/12 (2011$)

Fiscal Year	CIHR 226667	CIHR 98017	CIHR 146177	CIHR 167357	CIHR 61010	CIHR 64574	Historical Funding[a]	CIHR CTP Funding	Total Associated CIHR Funding[b]
2000/01					45,083		721,335	766,418	1,536,549
2001/02					89,163	71,438		160,600	872,380
2002/03					88,182	60,760		148,942	784,597
2003/04		58,945			42,682	58,819		160,447	703,703
2004/05		114,241						114,241	760,893
2005/06		17,332						17,332	1,025,663
2006/07		144,770	22,152					166,922	844,148
2007/08			97,640					97,640	600,588
2008/09			112,790	34,816				147,606	799,295
2009/10			130,735	106,465				237,200	476,191
2010/11				103,426				103,426	256,937
2011/12	38,673			100,000				138,673	138,673
Total	38,673	335,288	363,318	344,707	265,109	191,017	721,335	2,259,446	8,799,617

Note: Columns 2 through 7 are CIHR project numbers; grant and award titles are in the text. Source: Canadian Institutes of Health Research, 2012.

[a] Historical funding represents CTP-related research support from the Medical Research Council, the predecessor of CIHR, and the Heart and Stroke Foundation of Ontario. Some portions of MRC and other funding from the 1990s supported CTP development. These funds were adjusted and brought forward to 2000/01.

[b] Total associated CIHR funding includes funding for CTP research and the CIHR research funding for all other researchers associated with the CFI project applications that supported CTP research.

- CIHR 167357, Developing CT Functional and Molecular Imaging Techniques for the Diagnosis of Disease and Monitoring of Treatment Effects in Stroke, Cancer, and Heart Diseases
- CIHR 226667, Quantitative CT Myocardial Perfusion Imaging

Collectively, these operating grants represent $2,259,446 (2011 dollars) in research support through the close of FY2011/12.[1] These grants funded algorithm development, testing, and evaluation, including validation using CT scanning infrastructure.

Historical versions of Dr. Lee's curriculum vitae were obtained and reviewed with Dr. Lee to identify funding that preceded CIHR's creation that were essential to his CTP research. Doing so confirmed that public support was essential to CTP development and permitted inclusion of historical funding in the cost analysis for this case study. Although some aims of the projects supported non-CTP research objectives, the entirety of the amounts for the projects that follow were annualized, adjusted to 2011 dollars, and placed in a lump sum of $721,335 in 2000 to be included in the cost basis. The projects, funder, value, and period of performance were:

- Investigation of the Relationship between Cerebral Blood Flow Volume and Cerebral Blood Flow during Anesthesia and Changing $PaCO_2$, HSFO, $36,721, 1993–1995
- The Effects of Anesthetics and Hyperventilation on Cerebral Blood Volume and Cerebral Blood Flow in Rabbits and Changing $PaCO_2$, Canadian Anesthesia Society, $10,000, 1995–1996
- CT Functional Imaging, MRC, $34,436, 1995–1997
- CT Imaging of Cerebral Hemodynamics in Subarachnoid Hemorrhage, Berlex Canada, $27,896, 1996–1998
- Thrombolytic Therapy of Acute Stroke: CT Evaluation of Cerebral Blood Flow, Roche Canada, $75,000, 1997–1998
- Contrast Media Enhanced Functional Imaging, MRC, $46,527 (yearly), 1997–2001

[1] Future commitments for these grants total $584,705 for a total funding amount of $1,945,933.

CT Imaging of Cerebral Hemodynamics in Subarachnoid Hemorrhage. HSFO, $45,975, 1996–1998

The public investment specifically for the development of the enabling algorithms and protocol for CT Perfusion software is $9.2 million. All associated CFI project and CIHR research funding amounted to $44.78 million.

The CFI infrastructure was a foundation on which multiple research pillars stand. Lee's CTP R&D represents one of those pillars. The other pillars are the research programs for Frank Prato, Terry Thompson, Brian Rutt, James Koropatrick, Blaine Chronik, Peter Williamson, Savita Dhanvantari, Alex Thomas, and Jenan-Luc Urbain. A limitation is certainly that there are likely other users; however, it was these researchers in particular whose research agendas were peer-reviewed for award of both CFI research projects. Thus, their CIHR funding must be included in the cost basis.

After adjustment to real terms using real GDP (chained),

- the CTP-specific CIHR grants amount to $2,259,446 (2011$)
- all associated CIHR grants amount to $8,799,617 (2011$)

4.2.3 Combined CFI Project and CIHR Funding

The public investment specifically for the development of the enabling algorithms and protocol for CT Perfusion software is $9.2 million, of which 75% was for CFI projects and 25% was CIHR research funding.

The public investment related to the entire CFI projects and all associated CIHR research funding was $44.78 million, of which 80% was for CFI projects and 20% was CIHR research funding.

4.3 ADVANTAGES OF CT PERFUSION IN CANADIAN EMERGENCY DEPARTMENT SETTINGS

It is estimated that there are more than 50,000 hospitalizations per year for stroke in Canada and approximately 300,000 people are living with the effects of a stroke. A report prepared for Public Health Agency of Canada (PHAC) quantified the national cost of stroke for 2000 alone to be $3.6 billion (PHAC, 2009).[2]

[2] That estimate is composed of direct healthcare costs and the indirect costs of lost productivity and premature mortality.

A report prepared for the Public Health Agency of Canada quantified the national cost of stroke for the year 2000 alone to be $3.6 billion (PHAC, 2009).

CTP offers several advantages in Canadian emergency department settings for acute stroke. Current indications for thrombolysis are that tPA should be administered within 4.5 hours of stroke onset and ideally within 3 hours (Canadian Stroke Network, 2011). Time is of the essence. Interviews with leading neuroradiologists in Canada and the United States, as well as a review of the literature, emphasize the advantages of CTP:

- quantification of CBF, CBV, and MTT to inform acute stroke care;
- use of CT scanning technology that is readily and increasingly available in Canadian trauma settings (CIHI, 2012);
- lack of availability of MR scans in trauma settings, which would be the alternative to acquiring indicators in the absence of CT;
- rapidity with which CTP scans can be conducted, particularly because of lengthy travel times from location of stroke onset to trauma unit; and
- low cost and ease of use.

A cost-effectiveness analysis of using CTP for acute stroke diagnosis and patient selection for thrombolysis relative to unenhanced CT and MR was published in 2012 by Earnshaw et al. That study used a decision-analytic model in which clinical trial, costs, efficacy, and utility information was collected and analyzed from the published literature on stroke and CTP. That model concluded that inclusive of direct and indirect costs CTP both saved costs and enhanced quality of life. Patients selected for thrombolysis were determined to have 0.12 additional quality-adjusted life years (QALYs), on average, because of enhanced diagnosis and course of treatment decisions.[3]

The 0.12 QALY benefit estimate is used in this study as a measure of the social value of CTP to a person suffering from moderate to severe acute ischemic stroke.

[3] The range of QALY in Earnshaw et al. (2012) is 0.12 to 0.13. This paper uses the lower-bound estimate.

4.4 COUNTERFACTUAL DEVELOPMENT OF CT PERFUSION

In-depth interviews were conducted with Dr. Lee, CT scanning equipment vendors, and eleven noted and highly respected neuroradiologists and stroke neurologists, all of whom were active in stroke research and qualified to speak to CTP's impact and counterfactual development through reviews of their presentations and publications.

Estimation of economic benefits requires accurate specification of the counterfactual introduction to the healthcare market of CTP algorithms in the absence of CFI's and CIHR's support. In-depth interviews were conducted with Dr. Lee, CT scanning equipment vendors, and eleven noted and highly respected neuroradiologists and stroke neurologists working at stroke units in Canada and the United States, all of whom were active in stroke research and qualified to speak to CTP's impact and counterfactual development through reviews of their presentations and publications.[4]

With the exception of Dr. Lee, who spoke to the counterfactual evolution of his research program without CFI and CIHR support, interviewees were promised confidentiality in exchange for their willingness to offer candid assessments. Confidentiality was particularly important because, although the CT market is intensely competitive, it is common for leading physicians to consult with multiple vendors over the course of their career to support technology development and health research.

The consensus among participating neuroradiologists and stroke neurologists was that the CTP research (supported by CIHR using CFI funded infrastructure) and the licensing of the algorithms and protocols to GE Healthcare accelerated the clinical use of CTP between 5 and 7 years. Other experts who were interviewed simply stated "many" years or stated that there was an acceleration effect but they were uncertain how great that effect was.

These experts also estimated that without public funds not only would the introduction of CTP software have been delayed, but the software that would have emerged would likely have been inferior in the accuracy and precision of measurement of CBF, CBV, and MTT. Interviewees noted that Dr. Lee has an uncommon background beyond his research career as both an imaging physicist and a mathematician. This background coupled with what was characterized as an intense interest in

[4] These individuals also noted that physicians, technicians, and hospital administrators are important change agents in the assimilation of new imaging studies.

developing simple tools using readily available technology were offered in explanation of the novelty of Dr. Lee's accomplishments.

It was estimated that the CTP research (supported by CIHR and using CFI funded infrastructure) and the licensing of the algorithms and protocols to GE Healthcare accelerated the clinical use of CTP between 5 and 7 years.

Following GE Healthcare's release of CT Perfusion,[5] other manufacturers moved to emulate the work, with varying degrees of success. When challenged to support the claim of not only induced innovation (see O'Connor and Rowe, 2008) but also of inferior quality in the absence of Dr. Lee's research, interviewees noted that when first released CT Perfusion was using principles, such as deconvolution, that others were not using; yet within a span of 3 years, most competing software products had adopted those principles. Conversely, these same individuals noted that by the late 2000s most software products had matured and it became routine to see an advance first appearing in one package being emulated in another. It was noted that CT Perfusion can also be used for perfusion studies in the heart, the liver, and tumours, but other software products generally are not. Further, CT Perfusion is the benchmark software being used for clinical trials studying the efficacy of using CTP for stroke and cancer.

Despite anecdotal evidence and literature suggesting widespread usage, the prevalence of CTP is not well documented. The panel of neuroradiologists participating in this case study estimated prevalence in Canada at 40% to 60% in 2011, with a high of 70% and a low reported as unknown penetration for moderate to severe acute ischemic strokes.

4.5 ECONOMIC ANALYSIS OF CT PERFUSION

The economic analysis of CT perfusion requires the following elements:

- number of moderate to severe acute ischemic strokes per year,
- probability of visiting an emergency department with CTP capabilities,
- current prevalence and the rate of growth in CTP from its introduction in 2000,
- QALYs associated with using CTP,

[5] The term CT Perfusion, in which Perfusion is capitalized, refers to GE Healthcare's registered trademark and product name for its CTP software.

- monetary value imputed for each QALY,
- costs of conducting CTP studies, and
- public investment in CTP research.

Analyzing these data will provide an estimate of the dollar-denominated socioeconomic value of CTP.

Please note that the data tables in this chapter were extracted from an MS Excel spreadsheet model. Therefore, totals recalculated independently from data tables may not align to results because of independent rounding.

4.5.1 Estimated Annual Number of Moderate to Severe Acute Ischemic Strokes

Neuroradiologists and stroke neurologists participating in this study indicated that CTP was generally only used for moderate to severe acute ischemic strokes. Patients with TIA, hemorrhagic, or mild ischemic stroke are either contraindicated or not expected to receive a CTP study. Thus, our benefits calculations must be constrained so as not to overestimate benefits.

To estimate the relevant number of strokes, we analyzed data from a recent study that quantified the national number of strokes by stroke type. Unfortunately that study's results did not distinguish stroke severity. Therefore, a study performed in the United States on stroke severity was used to assign stroke severity to the Canadian data. We then converted the subsequent results to the Canadian Neurological Scale (CNS) for stroke severity and calculated the number of moderate to severe acute ischemic strokes. The balance of Section 4.5.1 describes the necessary calculations.

The number of acute ischemic strokes per year is the 5-year annual average calculated by Krueger et al. (2012), who analyzed administrative data for 2004 to 2009 from the Canadian Institute of Health Information (CIHI) Discharge Abstract Database to determine the number of hospital episodes with strokes. Rather than recalculate the number of

strokes per year, Krueger et al.'s estimate was assumed to be representative of all years.[6]

Table 4-3 shows the 5-year total and annual average breakdown of strokes by stroke type. Of the 41,994 strokes per year in Canada, 27,511 of them were ischemic strokes. This would be a conservative estimate for 2000 through 2004, in particular, because an assessment prepared by PHAC (2009) reports that the incidence of all strokes was likely higher in this period.[7]

Table 4-3. Estimated Number of Strokes for 2004–09

	Ischemic	Hemorrhagic	TIA	Total
2004–2009	137,557	28,746	43,669	209,972
5-Year Average	27511.4	5749.2	8733.8	41994.4

Note: Includes Quebec and excludes strokes in persons under the age of 20.
Source: Krueger, H., Lindsay, P., Cote, R., Kapral, M. K., Kaczorowski, J., & Hill, M. D. (2012). Cost avoidance associated with optimal stroke care in Canada. Stroke, 43(8), 2198–206.

The next step was to estimate the proportion of strokes that could be considered moderate to severe. Johnson et al. measured the severity of strokes using the NIH Stroke Scale (NIHSS) for Medicare Fee-For-Service patients (Johnson et al., 2000). Because a similar distribution was not available for Canada, Canadian stokes were assumed to be distributed similarly. Table 4-4 maps the Canadian stroke estimates onto the NIHSS distribution. The NIHSS scale goes from 1 to 31, ranging from least severe to most severe.

[6] Kruger et al. applied two exclusion criteria. First, hospital transfers were excluded in order to prevent one stroke episode from being counted more than once in the analysis. Second, the researchers excluded stroke episodes for those younger than 20 years old. Also, The CIHI database did not include data for Quebec. To estimate Quebec, the researchers used their CIHI data, broken down by age category, and then applied this to population figures for Quebec (Krueger, 2012).

[7] The age-standardized rate of hospitalization for stroke per 100,000 population has declined since 1980. PHAC notes that the decrease may reflect few hospital admissions because of changes in patterns of care, better preventative care and health management, and healthier habits. However, an aging population and increased rates of diabetes and obesity may cause the rate to increase again (PHAC, 2009).

Table 4-4. Severity of Acute Ischemic Stroke, NIHSS Scale

NIHSS Scale[a]	Percentage of Strokes	Number of Cases[b]
1	2.82%	776
2	2.26%	621
3	6.67%	1,835
4	6.93%	1,906
5	7.44%	2,047
6	10.52%	2,894
7	5.64%	1,553
8	5.13%	1,412
9	2.82%	776
10	8.98%	2,470
11	2.82%	776
12	4.10%	1,129
13	2.82%	776
14	2.82%	776
15	3.85%	1,059
16	1.54%	423
17	1.54%	423
18	5.13%	1,412
19	2.31%	635
20	2.31%	635
21	2.05%	565
22	1.54%	423
23	2.82%	776
24	2.31%	635
25	0.77%	212
26	0.77%	212
27	0.77%	212
28	0.00%	—
29	0.00%	—
30	0.51%	141

NOTE: Distribution Values Estimated from Johnston et al.

Sources:

[a] Johnston, K. C., Connors, A. F., Wagner, D. P., Knaus, W. A., Wang, X.-Q., & Haley, E. C. (2000). A Predictive Risk Model for Outcomes of Ischemic Stroke. Stroke, 31(2), 448–455.

[b] Krueger, H., Lindsay, P., Cote, R., Kapral, M. K., Kaczorowski, J., & Hill, M. D. (2012) . Cost avoidance associated with optimal stroke care in Canada. Stroke, 43(8), 2198–206.

The Canadian Neurological Scale (CNS) uses a different numbering system than the NIHSS. The CNS ranges from 0 to 12 with 0 being most severe and 12 being least severe. Nilanont et al. created a simple conversion formula to calculate CNS scores when given NIHSS scores (Nilaont et al., 2010). The formula is:

$$CNS = (NIHSS - 21) \div -2$$

Using NIHSS scores to create CNS scores has been verified in other work. Muir and other researchers verified the high correlation between NIHSS and CNS scores. A single observer made CNS and NIHSS scores for stroke patients entering an acute stroke center in the United Kingdom. An absolute correlation of 0.94 was observed between the two scales, a robust finding indicating that the two scales generally match up in stroke assessments (Muir et al., 1996).

Mapping the distribution in Table 4-4 and renumbering negative values to become 0 results provides a distribution of strokes on the CNS in Table 4-5.

Siposnik (2010) created a binning of stroke severity with mild (CNS ≥ 8), moderate (CNS of 5<8) and Severe (CNS of 0<5).[8] Applying this distribution of CNS severity to Table 4-5 above, there were 8,540 severe strokes and 7,340 moderate strokes (Siposnik, 2010). Thus, we estimate that the annual average of moderate to severe acute ischemic strokes in Canada was 15,880.

4.5.2 Estimated Prevalence of CT Perfusion

The Canadian Stroke Network (2011) estimated that 70% of stroke hospitalizations occur at facilities with thrombolysis capabilities. This probability was used as the probability that a person would arrive at a hospital with CTP capabilities. Applying that percentage to the estimated number of in-scope strokes (15,880) yields 11,116 stroke hospitalizations. Thus, the maximum number of CTP hospitalizations for which CTP could be performed is 11,116.

[8] Siposnik uses a CNS scale where CNS ends at 1. For purposes of this study we are using a CNS scale that ends at 0.

Table 4-5. Severity of Acute Ischemic Stroke, CNS Scale

CNS Scale[a,c]	Number of Cases[b] Ischemic
11	776
10.5	621
10	1,835
9.5	1,906
9	2,047
8.5	2,894
8	1,553
7.5	1,412
7	776
6.5	2,470
6	776
5.5	1,129
5	776
4.5	776
4	1,059
3.5	423
3	423
2.5	1,412
2	635
1.5	635
1	565
0.5	423
0	2,188

NOTE: Distribution Values initially Estimated from Johnston et al. Figure 1A using NIHSS. CNS scale values were obtained by applying formula[3] (NIHSS-23)/-2 = CNS, and lumping any values less than 0 into the 0 category.

Sources:

[a] Johnston, K. C., Connors, A. F., Wagner, D. P., Knaus, W. A., Wang, X.-Q., & Haley, E. C. (2000). A Predictive Risk Model for Outcomes of Ischemic Stroke. Stroke, 31(2), 448–455.

[b] Krueger, H., Lindsay, P., Cote, R., Kapral, M. K., Kaczorowski, J., & Hill, M. D. (2012). Cost avoidance associated with optimal stroke care in Canada. Stroke, 43(8), 2198–206.

[c] Nilanont, Y., Komoltri, C., Saposnik, G., Cote, R., Di Legge, S., Jin, Y., Prayoonwiwat, N., Poungvarin, N., Hachinski, V. (2010). The Canadian Neurological Scale and the NIHSS: Development and Validation of a Simple Conversion Model. Cerebrovascular Disease 30 (2), 120-126.

Interviewees estimated that the prevalence of CTP studies in Canada in 2011 was in the range of 40% to 60% of moderate to severe acute ischemic strokes. To estimate lower- and

upper-bound prevalence in years preceding 2011, CT Perfusion licensing information was obtained and analyzed (Table 4-6).[9] The data were transformed such that licensing activity for 2011 was set to 1.00. For each intervening year beginning in 2000, the ratio of cumulative activity to date to that for the entire period was estimated. For example, the ratio of 2006 cumulative licensing activity to that for 2011 was 0.461. The ratio was then applied to the prevalence in 2011 to estimate that for 2006. The estimated prevalence for 2006 was 18% to 28%.

Table 4-6. Estimated Prevalence of CTP for Acute Stroke Diagnosis, 2000—2011

Calendar Year	Estimated Cumulative Penetration, as a Proportion of Ultimate 2011 Penetration	Lower-Bound Estimated Penetration (40%, 2011)	Upper-Bound Estimated Penetration (60%, 2011)	Estimated Annual Moderate-Severe Acute Ischemic Strokes	Estimated Number of CTP Studies, Lower Bound	Estimated Number of CTP Studies, Upper Bound
2000	0.017	1%	1%	11,116	78	117
2001	0.068	3%	4%	11,116	303	454
2002	0.128	5%	8%	11,116	567	851
2003	0.198	8%	12%	11,116	881	1,321
2004	0.276	11%	17%	11,116	1,229	1,843
2005	0.369	15%	22%	11,116	1,641	2,461
2006	0.461	18%	28%	11,116	2,051	3,076
2007	0.552	22%	33%	11,116	2,456	3,684
2008	0.649	26%	39%	11,116	2,888	4,332
2009	0.738	30%	44%	11,116	3,283	4,924
2010	0.877	35%	53%	11,116	3,900	5,851
2011	1.000	40%	60%	11,116	4,446	6,670

[9] In the absence of time series data about growth in CTP usage, it was assumed that growth mimicked that of global CTP growth which was approximated by the annual number of issued licenses from only one CT scanner vendor. This means that Canadian usage is assumed to be the same as other countries'. This assumption is not unreasonable because Canada's installed base of CT scanners grew 68% from 303 to 508 between 2001 and 2011 (CIHI, 2012). Underlying raw data are confidential and are not approved for public release.

Because GE Healthcare has global exclusive rights to the algorithms, using the growth in licensing revenue implicitly assumes that Canadian adoption of CTP follows the same pattern as global adoption.

It is estimated that in 2011 between 4,446 and 6,670 CTP studies were performed in Canada. This range was estimated by applying the lower and upper bounds of the prevalence range to the relevant number of stokes per year.

4.5.3 Estimated QALYs Gained

Earnshaw et al. (2012) estimated the health outcomes benefits to be 0.12 quality-adjusted life years (QALYs). In economic studies, human health benefits are quantified in terms of QALYs, or the additional quantity of life an intervention offers a patient, recognizing the fact that the person has suffered an adverse health event or has an illness (see also Chapter 2). Assuming that this benefit has been constant over time, multiplying the estimated number of CTP studies by this benefit value yields a time series of the QALYs gained for stroke patients benefiting from CTP (Table 4-7).

Table 4-7. Estimated Gain in Quality-Adjusted Life Years from CTP, 2000—2011

Calendar Year	Estimated Number of CTP Studies, Lower Bound	Estimated Number of CTP Studies, Upper Bound	QALYs Gained per Stroke Case Receiving CTP Study[a]	Estimated QALYs Gained, Lower Bound	Estimated QALYs Gained, Upper Bound
2000	78	117	0.12	9.3	14.0
2001	303	454	0.12	36.3	54.5
2002	567	851	0.12	68.1	102.1
2003	881	1,321	0.12	105.7	158.6
2004	1,229	1,843	0.12	147.4	221.2
2005	1,641	2,461	0.12	196.9	295.4
2006	2,051	3,076	0.12	246.1	369.1
2007	2,456	3,684	0.12	294.8	442.1
2008	2,888	4,332	0.12	346.5	519.8
2009	3,283	4,924	0.12	393.9	590.9
2010	3,900	5,851	0.12	468.1	702.1
2011	4,446	6,670	0.12	533.6	800.4
Total	23,722	35,584		2,846.7	4,270.0

[a] Earnshaw et al., 2012.

4.5.4 Value of QALYs Gained

As in Krueger et al. (2012), the value of 1 QALY is the average annual Canadian wage regardless of the patient's age or work status. Therefore, three data series from Statistics Canada were acquired to monetize the QALYs:

- the average hourly wage for persons 15 or over (Statistics Canada, 2012c),
- the average number of working hours per week (Statistics Canada, 2012b), and
- the GDP index, which is used to adjust for the time value of money (Statistics Canada, 2012a).

Multiplying these data by the number of weeks per year (52) produced an average annual wage of about $43,515 for 2011 (Table 4-8). The data for 2000 through 2010 were adjusted using the GDP index presented in Chapter 3. Table 4-9 presents the value of QALYs gained for 2000 through 2011, before accounting for the cost of conducting CTP.

Table 4-8. Valuation of One Quality-Adjusted Life Year, 2000—2011

Calendar Year	Average Hourly Wage Rate[a]	Average Number of Hours Worked per Week[b]	Number of Weeks per Year	Annual Wage Rate	Annual Wage Rate (2011$)
2000	16.66	37.9	52	32,833.53	42,569.44
2001	17.21	37.3	52	33,380.52	42,797.26
2002	17.66	37.1	52	34,069.67	43,200.34
2003	18.05	36.5	52	34,258.90	42,052.55
2004	18.50	36.9	52	35,497.80	42,224.40
2005	19.09	37.2	52	36,927.70	42,528.90
2006	19.72	36.9	52	37,838.74	42,459.75
2007	20.40	37.2	52	39,461.76	42,913.82
2008	21.31	36.8	52	40,778.82	42,592.70
2009	22.04	36.0	52	41,258.88	43,926.33
2010	22.53	36.2	52	42,410.47	43,863.36
2011	22.99	36.4	52	43,515.47	43,515.47

[a] Statistics Canada. 2012c. Labour force survey estimates (LFS), wages of employees by type of work, National Occupational Classification for Statistics (NOC-S), sex and age group, unadjusted for seasonality, annual (current dollars unless otherwise noted), (CANSIM Table 282-0069). [b] Statistics Canada. 2012b. Labour force survey estimates (LFS), by total and average usual and actual hours worked, main or all jobs, type of work, sex and age group, annual (CANSIM Table 282-0028). Please see Table 3-5 for the GDP index used to adjust nominal dollars to real dollars.

Table 4-9. Valuation of Quality-Adjusted Life Years Gained, 2000—2011

Calendar Year	Estimated Number of QALYs Gained, Lower Bound	Estimated Number of QALYs Gained, Upper Bound	Annual Wage Rate (2011$)	Value of QALYs Gained, Lower Bound (million, 2011$)	Value of QALYs Gained, Upper Bound (million, 2011$)
2000	9.3	14.0	42,569.44	0.40	0.60
2001	36.3	54.5	42,797.26	1.55	2.33
2002	68.1	102.1	43,200.34	2.94	4.41
2003	105.7	158.6	42,052.55	4.45	6.67
2004	147.4	221.2	42,224.40	6.23	9.34
2005	196.9	295.4	42,528.90	8.37	12.56
2006	246.1	369.1	42,459.75	10.45	15.67
2007	294.8	442.1	42,913.82	12.65	18.97
2008	346.5	519.8	42,592.70	14.76	22.14
2009	393.9	590.9	43,926.33	17.30	25.96
2010	468.1	702.1	43,863.36	20.53	30.80
2011	533.6	800.4	43,515.47	23.22	34.83
Total	2,846.7	4,270.0		122.45	183.68

4.5.5 Estimated Costs of CTP Studies

The average incremental cost of a CTP study in 2011 was estimated to be $88.06 (Earnshaw et al., 2012), of which 80% was the cost of the contrast agent. As previously noted, the time for conducting the imaging study was estimated to be between 5 and 10 minutes, and the time for processing and interpreting the results is estimated to take no more than 5 to 6 minutes.

Even in real terms, it is unlikely that the costs for conducting a CTP study remained constant. Therefore, prior years' costs for CTP were estimated by deflating costs using the healthcare services component of the consumer price index (Statistics Canada, 2012d). Table 4-10 presents the costs of applying CTP in a stroke setting.

4.5.6 Estimated Benefits of Applying CTP in an Acute Stroke Setting

The net economic benefits for health plans and patients is therefore the monetized value of QALYs gained less the costs of conducting CTP (Table 4-11). We estimate that the value of QALYs gained to be between $122.45 million and $183.68 million. Less costs of conducting CTP, net economic benefits

Table 4-10. Costs of Performing CTP Studies in an Acute Stroke Setting, 2000—2011

Calendar Year	Estimated Number of CTP Studies, Lower Bound	Estimated Number of CTP Studies, Upper Bound	Estimated Cost per Study (2011$)	Estimated Cost of CTP Studies, Lower Bound (million, 2011$)	Estimated Cost of CTP Studies, Upper Bound (million, 2011$)
2000	224	337	77.22	0.01	0.01
2001	874	1,310	78.81	0.02	0.04
2002	1,637	2,456	80.68	0.05	0.07
2003	2,542	3,813	80.68	0.07	0.11
2004	3,546	5,319	81.06	0.10	0.15
2005	4,735	7,103	82.07	0.13	0.20
2006	5,918	8,877	82.97	0.17	0.26
2007	7,089	10,633	83.17	0.20	0.31
2008	8,334	12,501	82.54	0.24	0.36
2009	9,474	14,211	87.19	0.29	0.43
2010	11,257	16,885	88.51	0.35	0.52
2011	12,832	19,249	88.06	0.39	0.59
Total	68,463	102,694		2.01	3.02

Table 4-11. Estimated Benefits of CTP for Acute Stroke, 2000—2011

Calendar Year	Value of QALYs Gained, Lower Bound (million, 2011$)	Value of QALYs Gained, Upper Bound (million, 2011$)	Estimated Cost of CTP Studies, Lower Bound (million, 2011$)	Estimated Cost of CTP Studies, Upper Bound (million, 2011$)	Incremental Economic Benefit of CTP Studies, Lower Bound (million, 2011$)	Incremental Economic Benefit of CTP Studies, Upper Bound (million, 2011$)
2000	0.40	0.60	0.01	0.01	0.39	0.59
2001	1.55	2.33	0.02	0.04	1.53	2.30
2002	2.94	4.41	0.05	0.07	2.89	4.34
2003	4.45	6.67	0.07	0.11	4.37	6.56
2004	6.23	9.34	0.10	0.15	6.13	9.19
2005	8.37	12.56	0.13	0.20	8.24	12.36
2006	10.45	15.67	0.17	0.26	10.28	15.42
2007	12.65	18.97	0.20	0.31	12.44	18.67
2008	14.76	22.14	0.24	0.36	14.52	21.78
2009	17.30	25.96	0.29	0.43	17.02	25.53
2010	20.53	30.80	0.35	0.52	20.19	30.28
2011	23.22	34.83	0.39	0.59	22.83	34.24
Total	122.45	183.68	2.01	3.02	120.44	180.66

over the period of 2000 through 2011, before assessing attribution to Lee and public support, would be $120.44 million to $180.66 million. This range reflects the value to patients of additional quantity of life, after adjusting for the quality of that life (see also Chapter 2).

These benefits would be impacts attributable to CFI and CIHR if in the absence of their support Dr. Lee's research would not have been supported and no other entity in Canada or elsewhere developed commercially viable CTP algorithms before 2012. However, such a scenario is unlikely given that research about CTP was published (e.g., Wintermark et al. [2002a])[10] and given the nature of the highly competitive CT scanner market. Thus, the analysis turns to the question of how and when would the benefits in Table 4-8 have accrued in the absence of CFI and CIHR support.

4.5.7 Net Economic Benefits Attributable to CFI, CIHR, and Partners

Under the counterfactual scenario without CFI and CIHR, the consensus among neuroradiologists offering time estimates was that it would have been at least 5 years before commercially available CTP software would have been introduced.

Under the counterfactual scenario without CFI and CIHR, the consensus among participating neuroradiologists offering quantitative estimates of acceleration effects was that it would have been at least 5 years before commercially available CTP software would have been introduced globally. To quantify these benefits, actual benefits accrued less the corresponding value under a 5-year delay represents the net economic benefits attributable to CFI and CIHR.

Dr. Lee indicated that, without the operating support from CIHR and the CT scanning systems acquired through CFI infrastructure grants, his work would not have been commercialized by GE Healthcare. The entire benefit for the 5-year acceleration period is therefore attributable to CIHR, CFI, and partners.

[10] Dr. Wintermark's research in Lausanne, Switzerland, was concurrent with Dr. Lee's MRC-funded work in London, Canada, in the late 1990s.

We estimated the net economic benefits attributable to public support of CTP to be $87 million to $130 million between 2000 and 2011.

We estimate that the economic benefits attributable are between $87 million and $130 million (see Table 4-12). Delaying benefits 5 years and taking the difference between the actual benefits and counterfactual benefits equate to the benefit attributable to public support.

These are lower-bound estimates because experts reported that the quality of algorithms that would otherwise have been introduced would have been lower. This would mean that the slope of the CTP penetration curve would have been lower in the counterfactual scenario and thus the counterfactual benefits stream lower. However, our panel of experts was unable to measure such changes in quality, and the analysis, therefore, had to assume that the penetration curve under the counterfactual scenario was of the same slope as was estimated for 2000 to 2011.

Table 4-12. Economic Benefits of CTP Attributable to CIHR, CFI, and Partners, 2000—2011

Calendar Year	Economic Benefit of CTP Studies, Lower Bound (million, 2011$)	Economic Benefit of CTP Studies, Upper Bound (million, 2011$)	Economic Benefits under a 5-Year Delay, Lower Bound (million, 2011$)	Economic Benefits under a 5-Year Delay, Upper Bound (million, 2011$)	Attributable Economic Benefits, Lower Bound (million, 2011$)	Attributable Economic Benefits, Upper Bound (million, 2011$)
2000	0.39	0.59			0.39	0.59
2001	1.53	2.30			1.53	2.30
2002	2.89	4.34			2.89	4.34
2003	4.37	6.56			4.37	6.56
2004	6.13	9.19			6.13	9.19
2005	8.24	12.36	0.39	0.59	7.85	11.77
2006	10.28	15.42	1.53	2.30	8.75	13.12
2007	12.44	18.67	2.89	4.34	9.55	14.32
2008	14.52	21.78	4.37	6.56	10.15	15.22
2009	17.02	25.53	6.13	9.19	10.89	16.34
2010	20.19	30.28	8.24	12.36	11.95	17.92
2011	22.83	34.24	10.28	15.42	12.55	18.82
Total	120.44	180.66	33.83	50.75	87.00	130.49

4.6 SOCIOECONOMIC RETURN ON CFI AND CIHR FUNDING

4.6.1 Socioeconomic Return on CFI Projects for CT and CIHR CTP Funding Only

Public costs of $9.2 million for Dr. Lee's CT research are subtracted from the benefits stream to yield net benefits in Table 4-13. Thus, the net economic benefits attributable to public support of CTP are estimated to be $77.81 million to $121.30 million between 2000 and 2011.

Table 4-13. Net Economic Benefits Attributable to CIHR, CFI, and Partners (CT Costs Only), 2000—2011

Calendar Year	Attributable Economic Benefits, Lower Bound (million, 2011$)	Attributable Economic Benefits, Upper Bound (million, 2011$)	CT-Related Public Costs of CTP Development (million, 2011$)	Net Attributable Economic Benefits, Lower Bound (million, 2011$)	Net Attributable Economic Benefits, Upper Bound (million, 2011$)
2000	0.39	0.59	3.27	(2.88)	(2.68)
2001	1.53	2.30	0.73	0.80	1.57
2002	2.89	4.34	0.64	2.25	3.70
2003	4.37	6.56	0.16	4.21	6.40
2004	6.13	9.19	0.11	6.01	9.07
2005	7.85	11.77	0.02	7.83	11.75
2006	8.75	13.12	0.17	8.58	12.95
2007	9.55	14.32	3.46	6.09	10.86
2008	10.15	15.22	0.15	10.00	15.07
2009	10.89	16.34	0.24	10.65	16.10
2010	11.95	17.92	0.10	11.84	17.82
2011	12.55	18.82	0.14	12.41	18.69
Total	87.00	130.49	9.19	77.81	121.30

We calculated three measures of economic return on the CT-related costs: net present value (NPV), benefit-to-cost ratio (BCR), and internal rate of return (IRR).

Table 4-14 presents the PV of costs when a narrow cost basis of only CT-related project costs is included in the cost basis. Cash flows are discounted using the real social discount rate recommended by TBS based on Canada's economic opportunity

Table 4-14. Present Value of CIHR, CFI, and Partner Costs (CT-Related Costs Only), 2000—2011

Calendar Year	Period Number	CT-Related Costs (million, 2011$)	Present Value of Costs (million, 2011$)
2000	0	3.27	3.27
2001	1	0.73	0.67
2002	2	0.64	0.55
2003	3	0.16	0.13
2004	4	0.11	0.08
2005	5	0.02	0.01
2006	6	0.17	0.11
2007	7	3.46	2.02
2008	8	0.15	0.08
2009	9	0.24	0.12
2010	10	0.10	0.05
2011	11	0.14	0.06
Total		9.19	7.15

cost of capital (TBS, 2007), which is 8% per annum (Jenkins and Kuo, 2007). The PV of costs is $7.15 million.

The NPV is the present value (base year = 2000) of benefits less the PV of costs. Because costs are assumed to be incurred at the beginning of a period and benefits at the end, benefits are discounted one additional period than costs (see Chapter 2). Table 4-15 presents the PV of net attributable benefits. Subtracting the PV of costs from the PV of benefits yields an NPV between $39 million and $63 million (Table 4-16).

The BCR is the ratio of the PV of benefits to the PV of costs, using the same 8% social discount rate. Thus, under a narrow cost definition, the BCR of CTP is 7:1 to 10:1. This means that for every $1 invested in CTP, $7 to $10 accrued.

The IRR is 89% to 126%.

Table 4-15. Present Value of Economic Benefits Attributable to CIHR, CFI, and Partners, 2000—2011

Calendar Year	Period Number	Attributable Economic Benefits, Lower Bound (million, 2011$)	Attributable Economic Benefits, Upper Bound (million, 2011$)	Present Value of Attributable Economic Benefits Lower Bound (million, 2011$)	Present Value of Attributable Economic Benefits, Lower Bound (million, 2011$)
2000	1	0.39	0.59	0.36	0.54
2001	2	1.53	2.30	1.31	1.97
2002	3	2.89	4.34	2.30	3.45
2003	4	4.37	6.56	3.22	4.82
2004	5	6.13	9.19	4.17	6.25
2005	6	7.85	11.77	4.95	7.42
2006	7	8.75	13.12	5.10	7.66
2007	8	9.55	14.32	5.16	7.74
2008	9	10.15	15.22	5.08	7.61
2009	10	10.89	16.34	5.04	7.57
2010	11	11.95	17.92	5.12	7.69
2011	12	12.55	18.82	4.98	7.48
Total		87.00	130.49	46.79	70.19

Table 4-16. Measures of Socioeconomic Return on CTP (CT-Related Costs Only)

Measure	Value
Net economic benefits attributable to CFI/CIHR ($ million)	$77M to $121M
NPV of net benefits ($ million, base year = 2000)	$39M to $63M
Benefit-to-cost ratio	7:1 to 10:1
Internal rate of return	89% to 126%

4.6.2 Socioeconomic Return on All Associated CFI Project and CIHR Costs

The measures of economic return for CTP presented in Table 4-16 are for only the CT-related costs for CFI projects and CIHR funding for Lee's CTP research compared with the benefits of public CTP. However, as reviewed in Chapter 2, it is expected that socioeconomic impact analyses will use a portfolio approach where the returns from one or more research outcomes is compared with a meaningful set of those

outcomes. Therefore, the benefits of CTP were compared with all known medical-imaging R&D funding for the CFI infrastructure supporting CTP R&D and the CIHR health research relying on that infrastructure.

This next level of cost aggregation consists of the full costs for both CFI projects, including the MR components, and all CIHR grants and awards for investigators listed on the CFI project user list submitted on both CFI application forms.

When the benefits of CTP are compared with all associated infrastructure costs and research programs, the net benefits are $42.2 million to $85.7 million. The BCR is 1.5:1 to 2.3:1, and the IRR is 28% to 46%.

The total known cost to CIHR, CFI, and partners, including MRC, associated with this cluster of funded infrastructure and research was $44.78 million (2011$), of which CFI and partner funding totaled $35.98 million and CIHR funding totaled $8.80 million. These data are presented in Table 4-17.

When the benefits of CTP are compared with all associated infrastructure costs and research programs, the net benefits are $42.2 million to $85.7 million. The BCR is 1.5:1 to 2.3:1, and the IRR is 28% to 46% (Table 4-18).

Table 4-17. Net Economic Benefits Attributable to CIHR, CFI, and Partners (All Related Project Costs), 2000—2011

Calendar Year	All CFI Project Costs (million, 2011$)	All CIHR Costs (million, 2011$)	Total Public Costs (million, 2011$)	Net Attributable Net Economic Benefits, Lower Bound (million, 2011$)	Net Attributable Economic Benefits, Upper Bound (million, 2011$)
2000	7.90	1.54	9.43	(9.04)	(8.85)
2001	1.79	0.87	2.66	(1.13)	(0.37)
2002	1.56	0.78	2.35	0.55	2.00
2003	—	0.70	0.70	3.67	5.86
2004	—	0.76	0.76	5.37	8.43
2005	—	1.03	1.03	6.82	10.75
2006	—	0.84	0.84	7.90	12.28
2007	12.57	0.60	13.17	(3.62)	1.15
2008	8.97	0.80	9.77	0.38	5.45
2009	1.47	0.48	1.94	8.95	14.39
2010	1.72	0.26	1.98	9.97	15.94
2011	—	0.14	0.14	12.41	18.69
Total	35.98	8.80	44.78	42.21	85.71

Table 4-18. Measures of Socioeconomic Return on CTP (All Related Project Costs)

Measure	Value
Net economic benefits attributable to CFI/CIHR ($ million)	$42M to $86M
NPV of net benefits ($ million, base year = 2000)	$16M to $39M
Benefit-to-cost ratio	1.5:1 to 2.3:1
Internal rate of return	28% to 46%

4.7 SUMMARY

The measures of return on CTP alone are appealing, given their size. However, applying a narrow cost definition of only the CT portion of two CFI projects, and ignoring that other CIHR research was associated with the infrastructure, opens the evaluation up to skepticism and claims of cherry-picking costs.

Presenting returns as a BCR of 1.5-2.3 on a meaningful group of projects established by grant application data is an appropriate recognition of the portfolio nature of R&D management and the high-risk, high-reward nature of early-stage applied R&D.

The estimates provided in this case study reflect the benefits to Canadians of CTP for stroke alone; however, Dr. Lee and others are developing protocols and testing, with CIHR support, CTP for heart, liver, and tumour imaging.

These are lower-bound measures of return because benefits for research programs of the other infrastructure users were not calculated, yet the public costs for these programs were included. In this way, a portfolio approach to quantifying socioeconomic benefits can offer decision makers the accountability measures they require without valuing every outcome associated with the investment.

If one were to compare the benefits for CTP ($87 million to $130 million) with

- the total imaging investment in McGill, UBC, UT, and Western through FY2011/12, the benefits from CTP alone are sufficiently large to account for 19% to 28% of the $387 million invested in imaging research at these institutions, after adjusting for the time value of money.
- the total imaging investment in all Canadian universities through FY2011/12, the benefits from CTP are sufficiently large to account for 7% to 10% of the $1,033 million investment, after adjusting for the time value of money.

Ultimately, the high BCRs estimated in this case study reflect the inherent value of sophisticated, yet simple to use, diagnostic tools that can inform clinical care. The estimates provided in this case study reflect the benefits to Canadians of CTP for stroke alone; however, Dr. Lee and others are developing protocols and testing, with CIHR support, CTP for heart, liver, and tumour imaging.

5 Pilot Study Conclusions and Lessons Learned

This pilot study successfully implemented socioeconomic evaluation strategies in the Canadian R&D context, bridging challenges in attribution through partnership between research infrastructure and research program funders. The case of CT perfusion is an excellent example of the profound effect public support and acceleration of R&D in the public interest can have on health outcomes. The right tools were placed in the hands of researchers who knew what to do with them, and the support was there over the long term for researchers to put those tools to good use. The ultimate beneficiaries are stroke suffers whose doctors are better equipped to rapidly diagnose their condition and more confidently recommend a course of treatment.

The benefits from CTP are sufficiently large to account for 7% to 10% of the national CFI, CIHR, and partner investment in medical imaging R&D and related health research.

In addition to CTP, this pilot study examined many other important outcomes from four of Canada's leading medical imaging research communities. That benefits were not monetized for them is a reflection of the limitations of conducting socioeconomic analyses. Over the course of research outcomes it is often the case that one learns that so-called outcomes are research works in progress or have yet to mature sufficiently to be eligible for retrospective economic analysis.

It is also the case that resource and time limitations preclude the research team's ability to evaluate appropriately sophisticated technologies, such as the BrainWeb technology infrastructure at McGill. Several CFI and CIHR projects in this study supported early-stage basic research that expands our understanding of cognition, biomechanical, and neurological

processes, and disease that, in turn, supplies knowledge that enables applied clinical and technology research. Thus, it will likely be several more years before quantifiable socioeconomic benefits can be reasonably monetized retrospectively.

The remainder of this chapter highlights lessons learned over the course of the pilot study that should inform future analyses.

5.1 LESSONS LEARNED

Engagement with funded researchers and end users of the outcomes of researchers' R&D efforts is critical to implementing our socioeconomic impact analysis methodology and is necessary for the counterfactual evaluation method. Another critical component is access to key data elements to allow monetization of related investments and returns.

One of the principles of piloting a new study design or implementing an accepted study design in a new context, as is the case of this CFI-CIHR partnership, is to document lessons learned for future assessments. Three primary lessons learned over the course of this pilot study should be cafrefully considered by those wishing to take on a similar assessment.

First, determining the scope of the project is challenging but essential. A clearly defined scope facilitates identifying the cost basis constituting the denominator of the BCR as well as identifying expected outcomes for the numerator.

Determining the scope is always challenging, particularly when two research organizations with different classification or syntax systems collaborate to identify the cost base. Coordination can be managed if all parties agree upon definitions and search terms, as in this study, although it can take an exceedingly long time to complete because of a reliance on multiple parties and the need to validate consistent application of inclusion criteria.

Technology outcomes have different characteristics and economic roles that suggest which methods should be employed to measure socioeconomic impact. Identifying all the possible outcomes at the initiation of a project should help guide the selection of appropriate methodologies and direct attention to needed data.

Second, all calculations of socioeconomic impact must be considered as time-point calculations. Research builds on generated knowledge, and outcomes continue to accrue from past research investments. As new knowledge emerges now, benefits can also emerge. For example, tomorrow a clinical trial could conclusively determine that CT perfusion provides fewer QALYs, and lower returns in the area of stroke, but also show that it has greater gains for other health conditions.

Care must be taken to identify an appropriate point in time to undertake an assessment, because assessing the returns too early has real risks and can lead to a conclusion that a technology is without societal merit, when it may just not have matured sufficiently.

And finally, as eluded to above, identifying and accessing data necessary to generate a return on investment calculation pose many challenges. Sometimes data are proprietary, other times they are just not collected. Approaches to model or derive data from multiple sources are required.

References

Axel, L. 1980. “Cerebral Blood Flow Determination by Rapid-Sequence Computed Tomography: Theoretical Analysis.” *Radiology,* 137(3):679-86.

Bernstein, A., V. Hicks, P. Borbey, T. Campbell, L. McAuley, and I.D. Graham. 2007. “A Framework to Measure the Impacts of Investments in Health Research.” *Science, Technology and Innovation Indicators in a Changing World: Responding to Policy Needs*. Paris: OECD.

Canada Foundation for Innovation (CFI). 2012. *Projects Funded by the Canada Foundation for Innovation—Projects financés par la Fondation canadienne pour l’innovation*. Available at http://innovation.ca/.

Canadian Institute for Health Information (CIHI). 2012. *National Survey of Selected Medical Imaging Equipment, 2003–2011*. Ottawa: CIHI.

Canadian Institutes of Health Research (CIHR). 2012. Funded Research Database. Ottawa: CIHR. Available at http://www.cihr-irsc.gc.ca/e/38021.html.

Canadian Institutes of Health Research (CIHR). Open Operating Grant Program—Figure 1: Application and Funding Statistics OOGP and Related Programs. Ottawa: CIHR. Last modified June 29, 2012. http://www.cihr-irsc.gc.ca/e/44787.html#fig1

Canadian Stoke Network. 2011. *The Quality of Stroke Care in Canada*. Ottawa: Canadian Stroke Network.

de Lucas, E.M., E. Sanchez, A. Gutierrez, A. Consales Mandly, E. Ruiz, A. Fernandez Florez, J. Izquierdo, J. Arnaiz, T. Piedra, N. Valle, I. Banales, and F. Quintana. 2008. "CT Protocol for Acute Stroke: Tips and Tricks for General Radiologists." *RadioGraphics*, 28:1673-1687.

Earnshaw, S.R., C. McDade, A-M. Chapman, D. Jackson, and L. Schwamm. 2012."Economic Impact of Using Additional Diagnostic Tests to Better Select Patients with Stroke for Intravenous Thrombolysis in the United Kingdom." *Clinical Therapeutics*, 34(7):1544-1558.

Eastwood, J.D., M.H. Lev, M. Wintermark, C. Fitzek, D.P. Barboriak, D.M. Long, T-Y. Lee, T. Azhari, M. Herazu, V.R. Chilukuri, and J.M. Provenzale. 2003. *American Journal of Neuroradiology*, 24:1869-1875.

Griliches, Z. 1958. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." *Journal of Political Economy*, 66:419-431.

Hoeffner, E.G., I. Case, R. Jain, S.K. Gujar, G.V. Shah, J.P. Deveikis, R.C. Carlos, B.G. Thompson, M.R. Harrigan, and S.K. Mukherji. 2004. "Cerebral Perfusion CT: Technique and Clinical Applications." *Radiology*, 231(3):632-644.

Holdsworth, D.W. and M.M. Thornton. 2002. "Micro-CT in Small Animal and Specimen Imaging." *Trends in Biotechnology*, 20 n8(supplement):s34-39.

Hopyan, J., A. Ciarallo, D. Dowlatshahi, P. Howard, V. John, R. Yeung, L. Zhang, J. Kim, G. MacFarlane, T-Y. Lee, and R.I. Aviv. 2010. "Certainty of Stroke Diagnosis: Increment Benefit with CT Perfusion over Noncontrast CT and CT Angiography." *Radiology*, 255(1):142-153.

Howard, D., R. Brophy, and S. Howell S. 2012. "Evidence of No Benefit from Knee Surgery for Osteoarthritis Led to coverage Changes and Is Linked to Decline in Procedures." *Health Affairs*, 31(10):2242-9.

Industry Canada. 2007. *Mobilizing Science and Technology to Canada's Advantage*. Ottawa: Public Works and Government Services Canada. Available at http://www.ic.gc.ca/eic/site/icgc.nsf/vwapj/SandTstrategy.pdf/$file/SandTstrategy.pdf.

Industry Canada. 2009. *Mobilizing Science and Technology to Canada's Advantage: Progress Report 2009*. Ottawa: Industry Canada. Available at http://www.ic.gc.ca/eic/site/icgc.nsf/eng/h_04709.html.

Jenkins, G. and C-Y. Kuo. 2007. "The Economic Opportunity Cost of Capital for Canada—An Empirical Update." Queen's Economics Department Working Paper Number 1133. Kingston, ON: Queen's University.

Johnston, K.C., A.F. Connors, D.P. Wagner, W.A. Knaus, X.-Q. Wang, and E.C. Haley. 2000. "A Predictive Risk Model for Outcomes of Ischemic Stroke." *Stroke*, 31(2):448–455.

Kirkley, A, T.B. Birmingham, R. B. Litchfield, J.R. Giffin, K.R. Willits, C.J. Wong, B.G. Feagan, Donner, S.H. Griffin, L.M. D'Ascanio, J.E. Pope, and P. J. Fowler. 2008. "A Randomized Trial of Arthroscopic Surgery for Osteoarthritis of the Knee." *New England Journal of Medicine*, 359:1097-1107.

Krueger, H., P. Lindsay, R. Cote, M.K. Kapral, J. Kaczorowski, and M.D. Hill. 2012. "Cost Avoidance Associated with Optimal Stroke Care in Canada." *Stroke*, 43(8):2198-206.

Larivière, V. and P. Lemelin. 2012. *Scientific and Technological Impact of CFI Researchers' Papers and Patents in the Area of Medical Imaging, 1990-2010*. Report submitted to the Canada Foundation for Innovation by Observatoire des sciences et des technologies. February 29.

Link, A.N. and J.T. Scott. 1998. *Public Accountability: Evaluating Technology-Based Institutions*. Norwell, MA: Kluwer Academic Publishers.

Link, A.N. and J.T. Scott. 2011a. *Public Goods, Public Gains: Calculating the Social Benefits of Public R&D*. New York: Oxford University Press.

Link, A.N. and J.T. Scott. 2011b. "The Theory and Practice of Public Sector R&D Economic Impact Analysis." NIST Planning Report 11-01, Gaithersburg, MD: National Institute of Standards and Technology.

Lui, Y.W., E.R. Tang, A.M. Allmendinger, and V. Spektor. 2010. "Evaluation of CT Perfusion in the Setting of Cerebral Ischemia: Patterns and Pitfalls." *American Journal of NeuroRadiology*, 31:1552-63.

Mansfield, E., J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley. 1977. "Social and Private Rates of Return from Industrial Innovations." *Quarterly Journal of Economics*, 91:221-240.

Miller, J.C., M.H. Lev, L.H. Schwamm, J.H. Thrall, and S.I. Lee. 2008. "Functional CT and MR Imaging for Evaluation of Acute Stroke." *American College of Radiology,* 5(1):67-70.

Muir, K.W., C.J. Weir, G.D. Murray, C. Povey, and K.R. Lees. 1996. "Comparison of Neurological Scales and Scoring Systems for Acute Stroke Prognosis." *Stroke*, 27:1817-1820.

Nilanont, Y., C. Komoltri, G. Saposnik, R. Cote, S. Di Legge, Y. Jin, N. Prayoonwiwat, N. Poungvarin, and V. Hachinski. 2010. "The Canadian Neurological Scale and the NIHSS: Development and Validation of a Simple Conversion Model." *Cerebrovascular Disease*, 30(2):120-126.

O'Connor, A.C., and Rowe, B. R. 2008. "Public-Private Partnership to Develop Technology Infrastructure: A Case Study of the Economic Returns of DNA Diagnostics." *Economics of Innovation and New Technology,* 17(7):651-663.

Organisation for Economic Co-operation and Development (OECD). 2007. *Assessing the Socio-Economic Impacts of Public Investment in R&D.* DSTI/STP 26.

Organisation for Economic Co-operation and Development (OECD). 2012. *OECD Economic Surveys Canada*. June.

Parsons, M.W. 2008. "Perfusion CT: Is It Really Useful?" *International Journal of Stroke*, 3:41-50.

Public Health Agency of Canada. 2009. *Tracking Heart Disease and Stroke in Canada*. Ottawa: Public Health Agency of Canada.

Ruegg, R. and G. Jordan. 2011. *Guide for Conducting EERE Retrospective Benefit-Cost Studies*. Draft report to EERE. Washington, DC: U.S. Department of Energy.

Shah, Amisha, Jane Wang, Takayuki Yamada, and Laurie Fajardo. 2003. Digital Mammography: A Review of Technical Development and Clinical Applications. Clinical Breast Cancer April 2003.

Shetty, S.K. and M.H. Lev. 2005. "CT Perfusion in Acute Stroke." *Neuroimaging Clinics of North America*, 15(3).

Sinclair, A. 1998. *Medical Imaging Discussion Paper.* Report to Health Industries Branch, Industry Canada, Ontario, Canada. Report No.: 98-X11-C06-1534-1.

Siposnik, G. 2010. "Canadian Neurological Scale – Iscore." Available at http://www.sorcan.ca/iscore/cns.html.

Srinivasan, A., M. Goyalm, F. Al Azri, and C. Lum. 2006. "State-of-the-Art Imaging of Acute Stroke." *RadioGraphics*, 26:S75-S95.

Statistics Canada. 2012a. CANSIM (database). Table 380-0056—Gross domestic product (GDP) indexes, annual (2002=100).

Statistics Canada. 2012b. Labour Force Survey Estimates (LFS), by Total and Average Usual and Actual Hours Worked, Main or All Jobs, Type of Work, Sex and Age Group, Annual (CANSIM Table 282-0028).

Statistics Canada. 2012c. Labour Force Survey Estimates (LFS), Wages of Employees by Type of Work, National Occupational Classification for Statistics (NOC-S), Sex and Age Group, Unadjusted for Seasonality, Annual (current dollars unless otherwise noted) (CANSIM Table 282-0069).

Statistics Canada. 2012d. Table 326-0021—Consumer Price Index (CPI), 2009 basket, annual (2002=100 unless otherwise noted). CANSIM (database).

Summers, D. and R. Malloy. 2011. "CT and MR Imaging in the Acute Ischemic Stroke Patient: A Nursing Perspective." *Journal of Radiology Nursing*, 30(3):104-115.

Tassey, G. 2003. *Methods for Assessing the Economic Impact of Government R&D*. NIST Planning Report 03-01. Gaithersburg, MD: National Institute of Standards and Technology.

Tosteson, A.N.A., N.K. Stout, D.G. Fryback, S. Acharyya, B.A. Herman, L.G. Hannah, and E.D. Pisano. 2008. "Cost-effectiveness of digital mammography breast cancer screening." Ann Intern Med 2008; 148:1-10.

Treasury Board Secretariat of Canada. 2007. "Canadian Benefit-Cost Analysis Guide (Regulatory Proposals)." Catalogue No. BT58-5/2007.

Tremblay, G., S. Zohar, J. Bravo, P. Potsepp, and M. Barker. 2010. "The Canada Foundation for Innovation's Outcome Measurement Study: A Pioneering Approach to Research Evaluation." *Research Evaluation*, 19(5):333-345.

Wintermark, M., M. Reichart, J-P. Thiran, P. Maeder, M. Chalaron, P. Schnyder, J. Bogousslavsky, and R. Meuli. 2002a. "Prognostic Accuracy of Cerebral Blood Flow Measurement by perfusion Computed Tomography, at the Time of Emergency Room Admission, in Acute Stroke Patients." *Annals of Neurology*, 51(4):417-432.

Wintermark, M., M. Reichart, O. Cuisenaire, P. Maeder, J.-P. Thiran, P Schnyder, J. Bogousslavsky, and R. Meuli. 2002b. "Comparison of Admission Perfusion Computed Tomography and Qualitative Diffusion- and Perfusion-Weighted Magnetic Resonance Imaging in Acute Stroke Patients." *Stroke*, 33:2025-2031.