R&D Investment Opportunities and Public Funding

Frederick Kijek, Reza Ghazal
University of Ottawa - Canada

Abstract

This paper describes the result of the recent design of an R&D economic impact assessment framework developed to meet Canada's National Research Council's (NRC) strategic planning and performance evaluation needs. In Canada, not only there are a considerable number of science parks and incubators, but also a huge fund are available for R&D projects every year.

Although R&D spending has for some time been acknowledged as an economic engine for growth, through technological diversification and commercialisation, the political requirement to quantify the economic return on R&D investments is relatively recent. What we propose is a method for comparing the return in terms of economic contributions from various investment options and a tool to help measure the performance of existing R&D programs.

Prior to being considered by NRC for further expansion and adoption as a strategic planning and evaluation tool, our quantitative R&D economic impact model was tested by comparing seven "pre-defined" expenditure options. The resulting analysis ranked each option according to its relative economic impacts and contributions. This paper focuses primarily on the modeling methodology, generalized results and proposed improvements.

The framework itself is adapted from several trusted quantitative methods including econometric, benefit-cost, input-output and economic impact analysis. Both static and dynamic elements of R&D expenditure impacts were incorporated. The results of the analysis provided the components and data on which two separate R&D comparison indexes were created:

An R&D Economic Impact (EI) Index involving eleven coefficients and multipliers, including: four R&D multipliers (one backward and three forward multipliers for Investment, Consumption, and Export); six general impact multipliers (Output, GDP, Exports, Imports, Employment and Labour Income); a total factor productivity (TFP) coefficient (estimated using capital stock, intermediate inputs, labour, production and R&D expenditures)

A Benefit-Cost (BC) Ratio was developed from the present value of forecasted benefit streams, using lags from the dynamic productivity coefficients and the economic multipliers for Output to value the investment impacts.

Primary data was collected both from Canada's National Accounts and Input-Output Matrices, as compiled by Statistics Canada, as well as from the OECD.

Both the EI index and BC ratio where calculated for each of the seven R&D investment options and the results were presented as a ranking from least to most important economic contributors. As expected, the ranking reflected existing Canadian strengths in production/receptor capabilities, domestic inputs and established comparative advantages. Confidence in the results was strengthened by the similarities in the two separate rankings by the indicators as well as by the results of an independent ranking analysis using bibliometric methods.

The methodology of this paper can be used to the subject of science parks and technological incubators in the way that it provides a methodology of R&D project evaluations. In other words, the methodology presented in this paper can be applied to anywhere (related to R&D) that the government has a role in. Generally, public sector can interfere in science parks for two main objectives; participating in some projects (in terms of financing) and providing assistantship in general in order to preparing the suitable infrastructure and environment for incubators. Government's participation in R&D projects is usually due to lack of private sector participation's existing in those fields of research, just like as market failure.

1. Introduction

It is estimated that Canada spent over $13 billion (Cdn) in the past year on publicly funded R&D programs and initiatives with very little evidence regarding the return on investment that is expected to be achieved or how R&D funding could have been strategically optimised.

Historically publicly funded R&D investments in Canada were justified based mainly on a qualitative assessment of their socio-economic impacts and contributions. With an increasing number of alternative emerging technologies and science based growth opportunities to invest in, it is the initiatives that can substantiate their claims and differentiate themselves in quantitative terms that will receive public funding. With a large and growing number of R&D funding requests from competing agencies, institutions and departments, in Canada as well as in most OECD countries, a structured quantitative substantiation of the impacts are increasingly being required so that the requests can be properly evaluated and compared with other options and their public investment strategies justified at the political or executive (cabinet) level.

In this light, a framework was proposed to NRC to assist in both comparing their strategic options as they plan their future and evaluating the performance of their existing programs based on a more structured and quantitative approach.

The proposed R&D economic impact framework incorporates a number of known and trusted quantitative methods, including input-output analysis, econometric methods, benefit-cost analysis, risk analysis and general equilibrium analysis. Prior to the full development of this analysis framework a "reduced" version was proposed to initially demonstrate the model's potential and functionality. A series of seven R&D investment options were identified to test the model's predictive and strategic planning capabilities. This paper deals primarily with the design of this "reduced" or "demonstration" version of the proposed framework as well as the modeling results of the comparison of the seven R&D investment options. It also provides recommended adjustments to expand the effectiveness of the approach.

Therefore, in this paper we focus on the public part of R&D projects not private one. But the methodology can be applied to some projects in science parks and technology incubators in which it helps the public planner (government) to choose some projects among all projects to provide funds and/or subsidies or not.

2. Science Parks and Technological Incubators

2.1 Technological Incubators Background

The idea of technological incubator program emanated from the desire to encourage and support budding new start-ups in their critical years before reaching maturity (Hoy et al, 1991). Protection policies of infant industries have been existed from many decades ago, but following WTO and lots of mutually free trade agreement among countries the nature of protection has been undergone a huge changes, from protecting the output(s) of an industry to supporting the R&D processes and science and technology parks. In addition, the existence of a gap between academic research and industries' needs has increased the need to establishing science parks and technology incubators. Science parks and incubators can play a crucial role in devising a comprehensive approach, requiring an effective interface vis-à-vis both academia and business (Thomas, 2005).

There are lots of successful businesses which started from the science parks and technological incubators all over the world. The incubator increased the chances of the small firms graduating from the incubator to survive by supplying such basic services as assistance and consultation in varying areas, thereby helping to accelerate their rate of growth (Sherrod, 1999). Due to increase in the number of employees, a reduction of labor and operational costs, as well as increase in gross sales, net profit, net value and overall benefits to the entrepreneurs (Gatewood, 1985), the enterprises that began their life in an incubator have had a higher rate of success than those who did not (for examples see Cutbill, 2000, and Hanon and Chaplin, 2003).

The technological incubators provide a variety of services. They integrate financial, counseling and infrastructure services and they provide the initiator with location, financial assistance, business and marketing advise, professional guidance, and administrative support - all of which help the initiator to turn his initial idea into a new product, while reviewing its economic visibility, its uniqueness, advantages, and the expected market demand for the product (Frenkel et al., 2005). Also, these services because of their nature spread the spillovers among different bodies or projects. As such, the incubators constitute a source of new innovation and growth for an industry, encouraging the emergence of new technologies, supporting the creation of new jobs, and as a by-product preventing brain drain (Pleschak, 1997; Reynolds, 2000). At a local level, the incubator may be viewed as a means of local economic development, since it can induce the creation and development of new firms in a specific location (Shefer & Frenkel, 2003).

Technological and business incubators are a worldwide phenomenon. There is a considerable number of incubators all around the world in many countries like USA, France, Germany, Japan, England, Italy, Spain and Belgium and etc with different objectives including attracting branches of international companies in Spain and Belgium, transferring technology from the academia to the industry and commercializing Universities research outputs in France, regional economic development tool in Italy and creating new jobs in England, serving for small and medium size high-tech firms within innovation centers and science parks in Japan, and bringing more interaction among universities, research institutes, the private sector and public entities in Brazil. Technological incubators have emerged considerably for some non-industrialized economies such as China, Turkey, Brazil, South Korea and Indonesia. Thanks to generous and intensive government support, the program has proved successful and contributes to the development of the country's economy (OECD, 1997).

Regarding the emerging of science and technology parks in countries with different objectives, an important point comes to mind and that is establishing science parks and incubators is filling some gaps in economic development process. Countries with different statues of economic situation and in different stages of development create those science centers to satisfy their economic needs. Therefore making any decision about the science parks should take into account all the existing situation and economic development needs.

According to Reynolds (2000), it is estimated that there are some 3,000 incubators spread all around the world, which more than half of them established during the 1990s. Most of the incubators are affiliated with and activated by such public or private bodies, as government agencies, universities, research centers, and large technological firms (Culp, 1990). The growing number of technological incubators internationally points to the importance ascribed by governments to the development of business as a basis for the creation of economic activities and as a tool for promoting innovation and creating new jobs (Frenkel et al., 2005).

2.2 R&D, Technological Incubators, and the Role of Government

There is no doubt that the R&D activities and science parks are close terms and there is no need to discuss in detail the interrelation between these two subjects. But just in order to emphasizing that we know science parks are a part of innovation network. According to Albert and John (2004) a number of studies have examined the influence of being in a science park on various aspects of firm performance (e.g., growth and R&D productivity).

Although the principal purpose of the technological incubator is to help entrepreneurs successfully implement and commercialize their projects, the incubator also provides the following services regarding the R&D projects:

1. Assistance in determining the technological and marketing applicability of the idea and drawing up an R&D plan;
2. Assistance in obtaining the financial resources needed to carry out the project;
3. Assistance in forming and organizing an R&D team;

On the other hand, government can have a role in the following ways: 1) participation (like venture capital), 2) preparing the ground, 3) financing and 4) insuring (for example in the case of failure, pays some part of the costs). These activities can be summarized in initiating, providing incentives and

setting eligibility criteria. Also he can help incubators in providing suitable facilities for R&D activities, financing the R&D projects, assistance in finding complimentary financing. But the most important part in incubators regarding the government role is government participation in R&D projects. For example the government of the state of São Paulo in Brazil has been seeking technological innovations through the development of technology parks. These parks, recognized all over the world, not only create a high quality environment for Research and Development (R&D) activities but are also able to attract high-tech companies, introduce state-of-the-art technologies and be the foundation for the establishing of new technology-based industries.
As it is expected the presence of the government can be seen along the whole process of science parks and technological incubators activities or related affairs (like venture capital), starting from providing funds and preparing environment and infrastructure and ending to commercializing the output. There is little doubt that Government intervention to increase the supply of venture capital inherently assumes a link between that occurrence and enhanced economic development (Neil, 2000).
Therefore, making an analytical tool to help the government to rank the projects in terms of economic impacts including and not limited to job creation, enhancing the internationally competitive power and keeping the environment cleaner is the first priority. It can also be very useful in selecting and monitoring the projects in science and technological parks.
Based on what we mentioned above, our methodology in present paper can be applied to the Iranian's government participation in GSTP (Guilsn Science Technoloy Park), KSTP (Khorasan Science and Technology Park), SBTP (Sheikh Bahai Technology Park) and PTP (Pardis Technology Park). In other words, this evaluation tool can be used to make decision by government to select among sectors or projects (like ICT, Biotechnology, Agro-food, Environment-related projects, and …) to invest directly and by how much and/or just helping them in providing the basic needs. Since the intensity of R&D in Iran's economy is quiet low, the participation of Iran's government in projects of science and technology parks has a vital importance.

2.3 Canada's Clusters

National Research Center of Canada (NRC) globally for research and innovation is a leader in the development of an innovative, knowledge-based economy for Canada through science and technology. Also stimulating the growth of community-based *technology clusters* across Canada is an important part of NRC's business. NRC research institutes and networks are central hubs, bringing local and regional interests together with groups of innovative companies around a common area of technology. NRC and its partners are actively expanding research capabilities, building new facilities and augmenting knowledge and industry support networks from coast to coast. The NRC's institute, programs and technology centers are:

1. NRC Biotechnology Research Institute(NRC-BRI),
2. NRC Canada Institute for Scientific and Technical Information(NRC-CISTI),
3. NRC Canadian Hydraulics Center(NRC-CHC),
4. NRC Center for Surface Transportation Technology(NRC-CSTT),
5. NRC Herzberg Institute of Astrophysics(NRC-HIA),
6. NRC Industrial Material Institute(NRC-IMI),
7. NRC Industrial Research Assistance Program, (NRC-IRAP)
8. NRC Institute for Aerospace Research(NRC-IAR),
9. NRC Institute for Biodiagnostics(NRC-IBD),
10. NRC Institute for Biological Science(NRC-IBS),
11. NRC Institute for Chemical Process and Environmental Technology(NRC-ICPET),
12. NRC Institute for Fuel Cell Innovation(NRC-IFCI),
13. NRC Institute for Information Technology(NRC-IIT),
14. NRC Institute for Marine Biosciences(NRC-IMB),
15. NRC Institute for Microstructural Sciences(NRC-IMS),
16. NRC Institute for National Measurement Standards(NRC-INMS),

17. NRC Institute for Ocean Technology(NRC-IOT),
18. NRC Institute for Research in Construction(NRC-IRC),
19. NRC Integrated Manufacturing Technologies Institute(NRC-IMTI),
20. NRC National Institute for Nanotechnology(NRC-NINT),
21. NRC Plant Biotechnology Institute(NRC-PBI),
22. NRC Steacie Institute for Molecular Sciences(NRC-SIMS),

NRC stimulates the creation of new firms, jobs, exports, and investment growth within regions through its incubation facilities, a vital component in fostering technology clusters. Incubating companies receive added value from access to NRC expertise and facilities. Incubating companies and the IPF occupancy rate are important leading indicators of new company creation, attraction of venture capital and future investment in the cluster. In 2003-2004, NRC had 115 incubating firms, an increase of 30% over last year. Successful firms eventually graduate from IPFs and create jobs and wealth within their communities. Eleven tenants graduated from NRC IPFs in 2003-2004, similar to last year. The success of NRC's IPFs is also illustrated by demand. A total of 27,669 square metres of common and usable space was available to firms and this space was, on average, 86% occupied (see Table 4-2). New IPFs opened at NRC-IOT, NRC-IMI, and NRC-SIMS. An expanded facility is planned for NRC-IBD and new facilities are to open in Halifax at NRC-IMB in September 2004 and in Charlottetown at NRC-INH in 2005.

Location	**Total Area (in m²)**	**Status**	**Completion Date**	**% occupied**
Institute for Ocean Technology (formerly Institute for Marine Dynamics) (St John's, NF)	480	in operation	2003-2004	92%
Institute for Marine Biosciences (Halifax, NS)	2,787	construction	2004-2005	-
Institute for Information Technology (Fredericton, NB)	1000	in operation	2002-2003	15%
Biotechnology Research Institute (Montreal, QC)	9,800	in operation	1997-1998	100%
Industrial Materials Institute (Boucherville, QC)	2,180	in operation	2003-2004	52%
NRC Industry Partnership Facility, M-50 (Ottawa, ON), (shared facility with several Institutes)	1,650	in operation	1998-1999	100%
Steacie Institute for Molecular Sciences (Ottawa, ON)	1,872	in operation	2003-2004	100%
Institute for Biodiagnostics (Winnipeg, MB)	477 4,645	in operation design stage	1995-1996 2004-2005	100% -
Plant Biotechnology Institute (Saskatoon, SK)	6,914	in operation	2002-2003	97%
Institute for Fuel Cell Innovation (Vancouver, BC)	600	in operation	1999-2000	67%
Herzberg Institute of Astrophysics (BC) Penticton Facility Victoria Facility	114 125	in operation in operation	2001-2002 2001-2002	0% 0%
Institute for Nutrisciences and Health (Charlottetown, PEI)	900	design stage	2005-2006	-
Institute for Chemical Process and Environmental Technology (Ottawa, ON)	492	in operation	1992-1993	23%
Integrated Manufacturing Technologies Institute (London, ON)	107	in operation	2003-2004	87%
Total	**34,143**			

Reference: NRC's reports

Table 4-2: NRC's Industry Partnership Facilities - Current and Planned

3. Project Objectives

The overall objective was to develop a multi purpose quantitative economic analysis tool to:

- strategically compare research funding options based on their relative economic return on investment

- perform economic performance evaluation of NRC's projects and/or programs

It was important to quickly develop a demonstration version of the tool to help with the agency's recent "Renewal" process and justify the further refinement and expansion of the tool.

4. Methodology & Framework Components

To develop the initial "demonstration" framework and model, the economic impacts and benefits were estimated using two well-known methods: input-output analysis and econometric modeling. Therefore both static and dynamic aspects of the R&D expenditures impacts were taken into account.
The initial framework includes the identification of the demonstration cases, the identification and collection of relevant data, development of the comparative economic impact indicators and an analysis of results.
The overall approach used is outlined in the process model diagram on the following below.

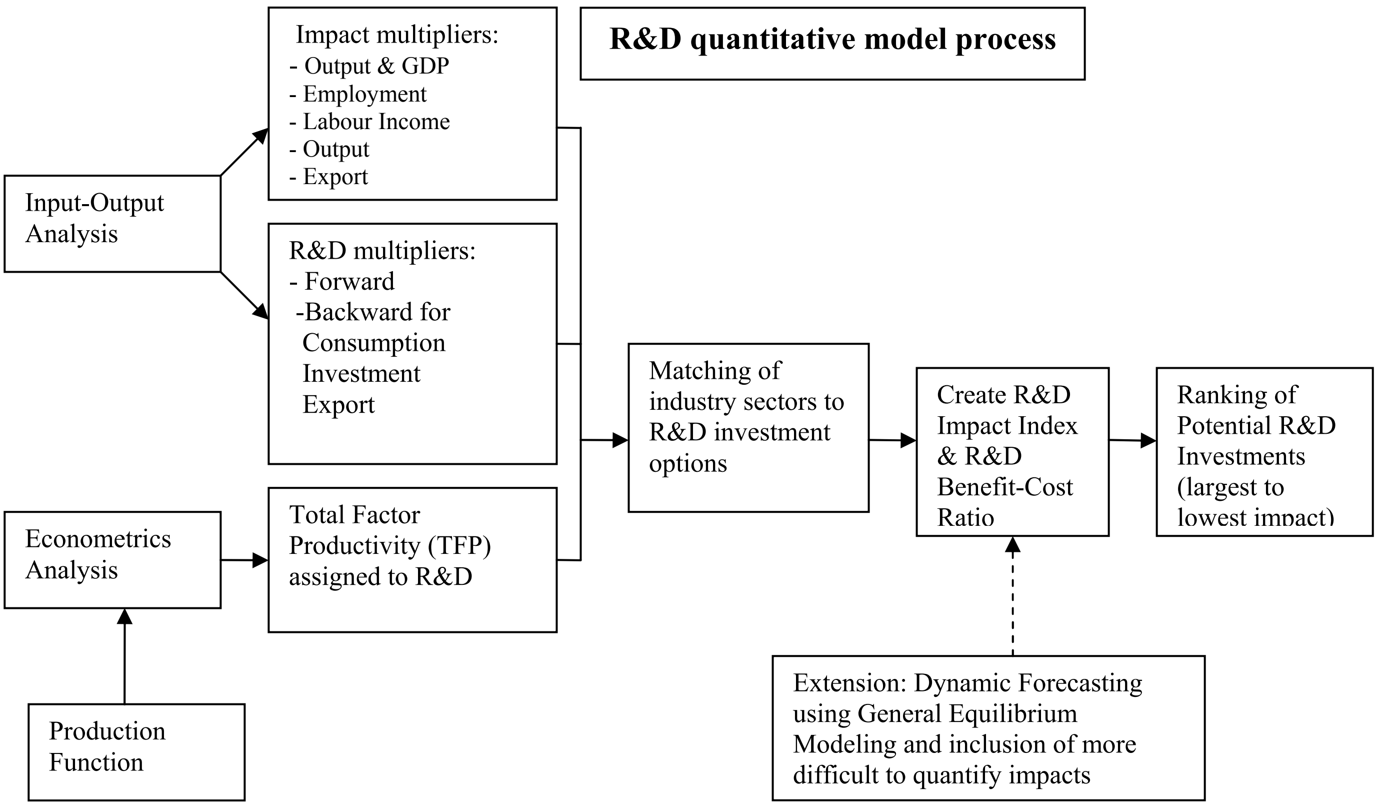


Diagram 1: R&D Quantitative Modeling Process

As can be seen above, a series of impact multipliers and coefficients are created for all sectors of the economy. Following a matching of economic sectors to investment options, two separate comparison indices are created and a ranking of the options in terms of their comparative impacts and contributions is presented.

4.1 R&D Impact Index

The R&D Impact Index was developed using both econometric modeling and input-output analysis to estimate its components. These components included a Total Factor Productivity (TFP) coefficient, four separate R&D Multipliers and six general economic impact multipliers.

4.1.1 Total Factor Productivity

The econometric approach allowed for the dynamic effects of each R&D expenditure to be introduced into the analysis. Specifically it computed the impact of an R&D investment on total factor productivity (TFP). The approach not only provided a coefficient to identify the impact of one extra dollar of R&D on increasing the TFP for a specific industry sector but also provided an estimate of the timeframe (lag) for the impacts to occur.

Data was collected from 39 industry sectors for output, labor, capital stock, intermediate inputs, exports, consumption, investment and R&D expenses.

For calculating the effects of R&D on TFP, a two-staged approach was adopted. This approach for estimating the impact of R&D on TFP borrowed from recent work done by the Congressional Budget Office as well as work done by the OECD.

First, since the total factor productivity values were not available for the 39 industries for which we had data, we estimated the production functions of each to get proxy values for TFP for those sectors. In estimating the production functions, we used the data on production, labor, and capital stock from Statistics Canada and intermediate inputs from an OECD database. Second, regression equations were estimated where the dependent and independent variable were the TFP proxies and total R&D investments respectively for each sector. By estimating the second series of equations we were able to analyze the influence of R&D on productivity.

A side benefit of estimating the TFP equations was that it provided the number of lags for different industries. In other words, based on these estimated equations we were able to identify how long the R&D investment might require in order for the impacts to be felt (i.e. lag structure).

4.1.2 R&D multipliers

We estimated both the backward and forward R&D multipliers for consumption, investment and export for each of the sectors for which data was available. The forward multiplier identifies, based on one extra dollar in R&D investment, what proportion is directed towards consumption, investment and exports. The backward multiplier reflects the direct and indirect embodiment of R&D per dollar of final demand for each product.

The methodology used in estimating these multipliers was borrowed from recent work undertaken at the SOM Research Institute in the Netherlands and relies heavily on Input-Output analysis and matrix manipulation.

For estimating the R&D multipliers, we used the 2001 Input-Output tables from Canada's National Income Accounts.

4.1.3 General Impact Multipliers

As mentioned, six general economic impact multipliers were used in this analysis framework, including for Output, GDP, Exports, Imports, Employment and Labour Income. These impact multipliers were estimated directly by Statistics Canada for 300 sectors.

4.1.4 Constructing the Index

Once we had estimated the three main components (TFP R&D impact coefficient, R&D multipliers, the GEI multipliers) we then had to align the sectors with the investment options.

A non-weighted averaging of data from various representative sectors essentially formed new proxy sectors for each investment option. This was done since we did not possess data for each specific sector that can be defined by the North American Industry Classification System (NAICS) codes (which underlie Canada's national accounting system). This was also done because each of the investment options straddled more than one sector in the input-output tables. These proxy sectors were chosen to reflect the underlying economic links and interrelationship inherent in the identified investment options.

We then created an index based on a straight multiplication of the TFP coefficient by an average of the four R&D multipliers and an average of the six general impact multipliers. The final ranking of the options was based on those indices.
The investments were then ranked based on this index from high (largest R&D economic impacts) to low.

4.2 R&D Benefit-Cost Ratio

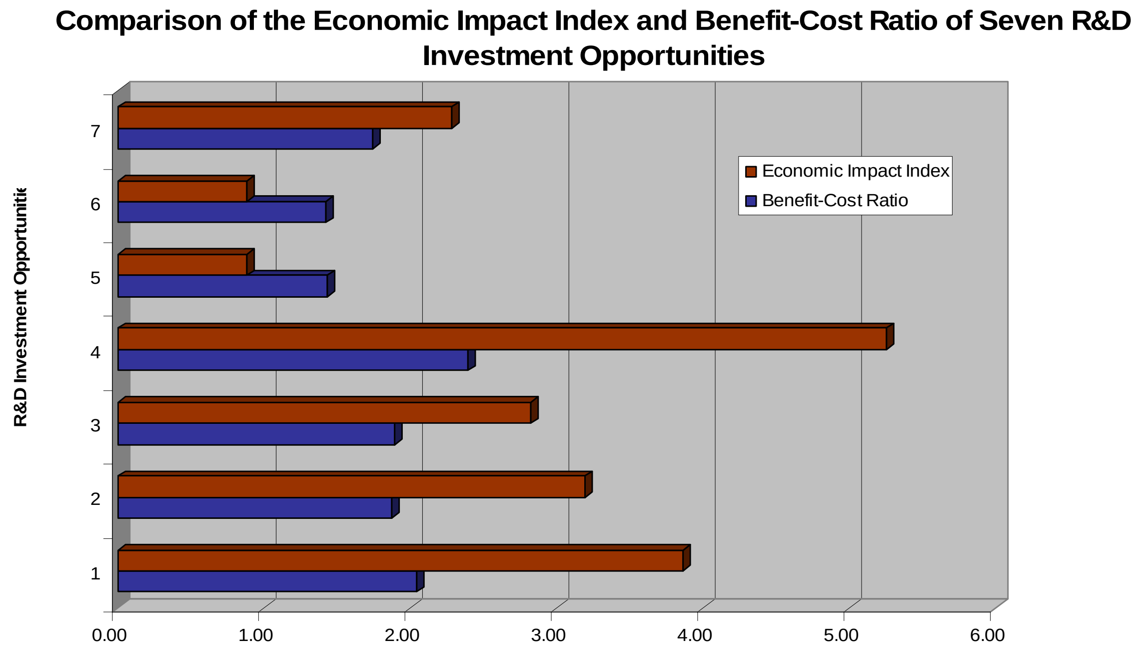
A Benefit-Cost ratio was developed from the present value of forecasted benefit streams, using lags developed as part of the estimation of the Total Factor Productivity coefficients. Output multipliers from each of the investment sectors were used as an estimate for the benefit streams, which were introduced according to the estimated productivity lags. As the individual costing of the investment options had not yet been estimated at the time of our analysis, the investment options were compared based on a similar R&D budget of $100 million (Cdn).
The R&D BC Ratios for each option were then ranked from high (largest Benefit-Cost Ratio) to low.

5. Results Overview

The table below provides the ranking of the R&D investment opportunities based on the analysis results using both comparative indicators. As can be seen from Table 1 and Diagram 2, both the ranking based on the R&D Impact Index and the R&D Benefit-Cost Ratio provided very similar results.
The results indicate that investments in the Resource and Energy related sectors (i.e. opportunities #4 and #1) provide the higher returns in terms of economic impacts and net benefits.
In addition, the indicators show relatively consistent, however slightly different ranking results (specifically with respect to R&D investment opportunities #2 and #3). This slight difference is due primarily to the dynamic nature of the benefit-cost analysis relative to the economic impact index (i.e. timing considerations of the impacts).

Opportunities Ranking based on R&D Economic Impact and Benefit-Cost Analysis Model Results			
Opp #	R&D Investment Opportunities	R&D Benefit-Cost Ratio	R&D Economic Impact Index
1	Enhanced energy technologies and alternatives sources	2	2
2	Sustainable advanced technologies and bioproducts for industrial applications.	4	3
3	Environmental technologies	3	4
4	Natural Resources	1	1
5	Chronic Diseases of the ageing population	6	6
6	Pandemics and Infectious Diseases	7	7
7	Water	5	5

Table 1: Ranking of Investment Opportunities using the R&D BC Ration and EI Index



	1	2	3	4	5	6	7
Economic Impact Index	**3.86**	**3.20**	**2.82**	**5.26**	**0.88**	**0.88**	**2.28**
Benefit-Cost Ratio	**2.04**	**1.87**	**1.90**	**2.40**	**1.44**	**1.43**	**1.75**

Diagram 2: Comparison of Investment Option Rankings

By decomposing the indices by individual impact multipliers and coefficients, the results could also be used to better understand the export creation, productivity improvements, and job creation impacts resulting from each investment. This is further illustrated in Diagram 3 on the following page.

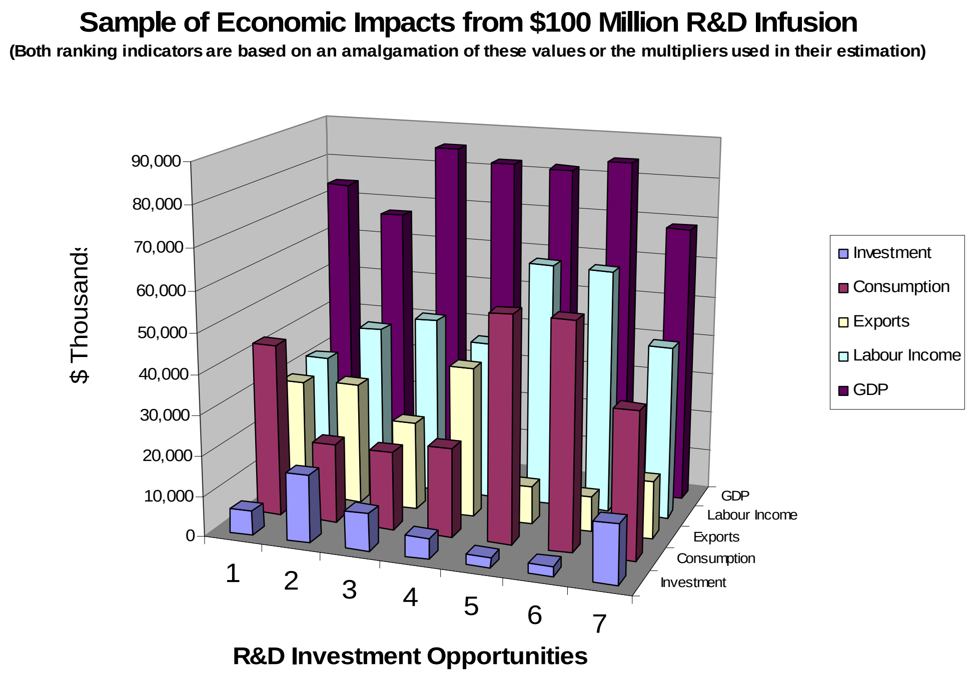


Diagram 3: Value of Economic Impacts by Investment Option

The overall results of the analysis confirm the expectation that the highest returns should parallel the economic sectors in which Canada presently has strong productive capabilities, existing infrastructure, available domestic inputs and strong established comparative advantages. The higher ranked opportunities will also include sectors for which Canada has been able to generate historically higher productivity and economic impacts from R&D expenditures.
The fact that the two ranking generate very similar results provides some comfort and a certain level of validation. These results were also compared and validated with a an independently prepared bibliometric analysis, where the same seven investment options were assessed based on potential economic contributions measured in terms of the number of publication and patents.
The seven investment options chosen are outlined in Table 1. It is important to note that as this was a demonstration project of the framework, the "pre-identified" investment options were broadly defined. This was somewhat deliberately to facilitate an iterative process for formulating gradually more specific strategic planning options. Although our analysis did benefit from more specific information regarding the magnitude and specific intended focus of each of these investment options, this information cannot be divulged for proprietary reasons, which also contributed to our identifying the investment options is broad sectoral terms.

5.1 Dynamic Forecasting & Risk Analysis

In addition to the lags used within our R&D BC Ratio Index to determine when in time the impacts might to be felt, a more structure forecasting capability should also be incorporated into the framework, as a better understanding of the magnitude of an impact within the context of a dynamic, future, economic structure is required. This would be better accomplished using computable general equilibrium (CGE) modeling, not only to better estimate future impacts but also to include other type of impacts more specific to R&D, such as spillover effects, into the analysis. This could be done by expanding a previously designed R&D CGE model that was developed within another department of the Government of Canada but whose analysis results are at present too aggregated to be useful in specific R&D performance evaluations and/or return on investment comparisons.

We are also presently working on identifying and developing a more quantitative approach to traditional foresight techniques in an attempt to introduce them into our quantitative framework.

6. Conclusions

Regardless of the identified weaknesses of the "demonstration" framework there is a definite and unambiguous need for the public R&D communities to adopt more quantitative approaches and tools in evaluating their programs and their strategic planning options. We believe that an innovative approach based on IO and Econometric methods is a sound, robust and effective method and is worth expanding.
The proposed, fully "expanded", framework is outlined in the diagram on the following page. As can be seen, the expanded version of the model would include more refined sector analysis capabilities required for economic performance evaluation purposes as well as more elaborate and dynamic forecasting methods, such as computable general equilibrium modeling (CGE). It would also include more difficult to quantify social benefits and impacts, such as those generated from a reduction in hazardous emissions or improved health care.
Risk analysis will also be included into the framework to ensure that the variability and uncertainty in the data, and forecasted results, is properly accounted for in the R&D investment comparison or evaluation results.

Expanded Public R&D Investment Comparison Framework

Diagram 4: Proposed "Expanded" Quantitative R&D Analysis Framework

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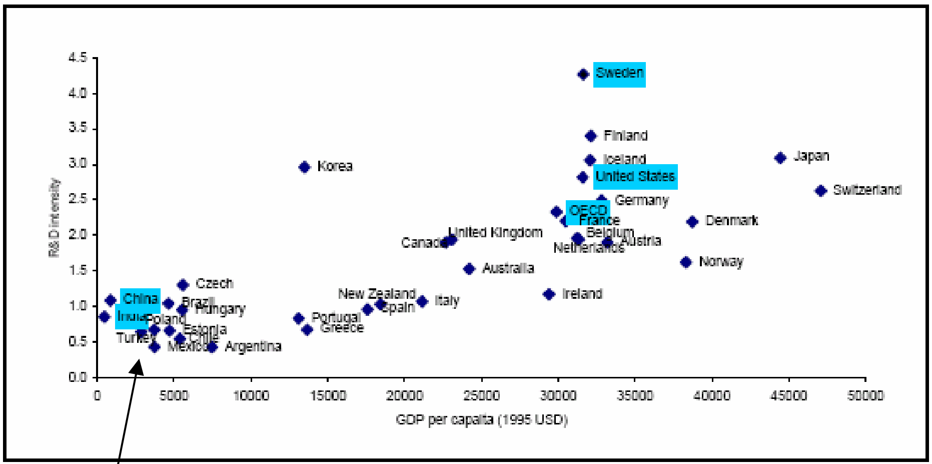
Figure 1. R&D intensity[1/]



1. Research and development expenditures relative to GDP

Possible position of Iran in R&D