



THE STATE OF INDUSTRIAL R&D IN CANADA

The Expert Panel on the State of Industrial
R&D in Canada



Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

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THE COUNCIL OF CANADIAN ACADEMIES

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Library and Archives Canada Cataloguing in Publication

The state of industrial R&D in Canada / The Expert Panel on the State of Industrial R&D in Canada.

Issued also in French under title: L'état de la R-D industrielle au Canada.

Includes bibliographical references.

Issued in print and electronic formats.

ISBN 978-1-926558-59-2 (bound).--ISBN 978-1-926558-60-8 (pdf)

1. Research, Industrial--Canada. 2. Technological innovations--Canada.

I. Council of Canadian Academies. Expert Panel on the State of Industrial R&D in Canada, author II. Title: State of industrial research and development in Canada.

T177.C2S73 2013

607'.271

C2013-904302-0

This report should be cited as:

Council of Canadian Academies, 2013. *The State of Industrial R&D in Canada*. Ottawa, ON: The Expert Panel on Industrial R&D in Canada, Council of Canadian Academies.

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Printed in Ottawa, Canada



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Message from the Chair

Over the past several decades, both employment and economic growth in Canada have been strong. In fact, Canadians enjoy one of the highest standards of living in the world. Our post-secondary education sector is world leading, both in terms of scientific contributions and well-trained graduates. However, just below the surface of this economic and social prosperity lie some troubling trends. Canadian GDP per capita remains roughly only 80 per cent of the U.S. level, Canadian labour productivity growth lags behind that of the United States and many other countries, and Canadian innovation is generally deemed sub-par.

Since industrial research and development (IR&D) is an important contributor to the innovation process, it is not surprising that it has been a source of perennial concern for Canadian policy-makers. This concern led to the formation of the Expert Panel on the State of Industrial R&D in Canada. The Panel examined the best available data and academic literature to assess the state of IR&D in Canada. Over many deliberations, the Panel struggled both with data limitations and the challenge of understanding the complex relationships between IR&D and other indicators of academic research, innovation, productivity, and standard of living. It is here where I think the Panel's work is most important and interesting, yet also the most incomplete. We have identified key areas for further study, which we hope will be taken up by others. While this assessment has been challenging, I am confident the final report clearly assesses the state of IR&D in Canada, and will serve as an important baseline for evaluations and decisions going forward.

On behalf of my colleagues on the Expert Panel, I would like to thank the reviewers who took the time to critique this report to ensure it was balanced and evidence-based, featuring useful analysis for its Sponsor.

Finally, the Panel and I could not have produced a report of this calibre without the assistance and intellectual contributions of Council staff under the expert guidance of its President, Elizabeth Dowdeswell.



Kathleen Sendall, C.M., FCAE

Chair, Expert Panel on the State of Industrial R&D in Canada

Acknowledgements

Over the course of its deliberations, the Panel sought assistance from many individuals and organizations that provided valuable evidence and information for consideration. Special thanks go to the following: Ian Currie, consultant and researcher; Greg Peterson, Louise Earl, and Ziad Ghanem of Statistics Canada; Eric Archambault, Grégoire Côté, and colleagues at Science-Metrix; Janice C. Simpson of Redoaks Management Consulting Inc.; Peter Jarrett and Alexandra Bibbee of the OECD; and Professor Bev Dahlby of the University of Alberta.

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Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and non-governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the Council.

The Council wishes to thank the following individuals for their review of this report:

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Elizabeth Dowdeswell, O.C., President and CEO
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Executive Summary

Industrial R&D (IR&D) is the private sector's investment of time and resources in the development of new ideas, technologies, and processes to promote business performance and create better products. IR&D also contributes to meeting pressing social challenges, ranging from development of new medical treatments to mitigation of environmental impacts to changing the ways in which Canadians work together. The returns on investments in IR&D can be high for the firms undertaking it, the economy at large, and, in particular, the region in which the IR&D takes place.

IR&D and innovation are not synonymous. IR&D consists of any scientific research or technology development undertaken by Canadian businesses. Innovation, on the other hand, is a broader concept that can be defined as “new or better ways of doing valued things.” IR&D is a critical driver of innovation, which, in turn, plays an important role in catalyzing productivity gains across the economy, thereby stimulating wealth creation and improving living standards for all Canadians. The historically low rate of investment in IR&D in Canada compared to other countries is one of the key factors that also accounts for the consistently wide gap in productivity growth between Canada and the United States.

CHARGE TO THE PANEL

For most of the 20th century, and now into the 21st, Canadian policy-makers have attempted to craft policies to better promote IR&D and innovation in Canada. Understanding the current state of IR&D is critical to effective policy development. In 2011 the Minister of Industry, on behalf of Industry Canada, asked the Council of Canadian Academies (the Council) to respond to the following charge:

What is the current state of industrial research and development (IR&D) in Canada?

- *What are Canada's industrial R&D strengths? How are these strengths distributed by sector and geographically across the country? How do these trends compare with what has been taking place in comparable countries?*
- *In which scientific disciplines and technological applications are our relative strengths most aligned with Canada's economic strengths/industry needs?*
- *What are the key barriers and knowledge gaps in translating Canadian strengths in S&T into innovation and wealth creation?*

The Council assembled a panel of 14 leading experts (the Panel) with a diverse range of professional and academic expertise. The Panel's focus was R&D undertaken by, or at the direction of, Canadian businesses (i.e., IR&D). This assessment complements the Council's 2012 assessment of Canada's S&T strengths, primarily as embodied in the research efforts in Canada's higher education sector and in government.

ASSESSING THE STATE OF IR&D IN CANADA

Assessing the state of IR&D in Canada is a complex undertaking. The Panel examined measures of IR&D inputs (expenditures and personnel), outputs (patents and scientific publications), and outcomes (rates of innovation and other economic outcomes). The Panel's detailed analysis of patenting and scientific publication patterns at the industry level is the first of its kind in Canada. In addition, the Panel identified and assessed Canada's IR&D strengths based on selected measures of magnitude and intensity, impact and quality, and trends.

THE STATE OF IR&D IN CANADA

The Canadian business sector invests relatively little in IR&D compared to peers abroad, although some industries are highly IR&D intensive by international standards. The first part of this finding is consistent with previously published studies, and continues to be troubling given Canada's persistent record of relatively low productivity growth. Most significantly, the low level of IR&D investment suggests that IR&D is not the principal strategy followed by many Canadian firms in maintaining their competitiveness. Expressed as a share of GDP, IR&D expenditures in Canada are now roughly half the U.S. level and declining. Several Canadian industries, however, show higher IR&D intensities than those of other G7 countries. These include communications equipment manufacturing, office and computing machinery manufacturing, coke and refined petroleum products manufacturing, and pulp and paper.

The IR&D intensity gap between Canada and the United States is largely driven by Canada's low IR&D intensity in the manufacturing sector.

The relatively large share of the Canadian economy accounted for by natural resource industries has almost no impact on this gap. Instead, some of Canada's high-technology manufacturing industries, such as semiconductor and computer equipment manufacturing, form a smaller share of the economy in Canada than in the United States. This smaller size drags down the manufacturing sector's aggregate IR&D intensity. The declining share of these high-technology manufacturing industries in the Canadian economy in recent years has further

exacerbated this effect. While a relatively high degree of foreign ownership may act to lower IR&D in some industries, such as motor vehicle manufacturing, it is unlikely that this fully explains the overall picture in Canada.

Many industries that traditionally do not spend as much on IR&D have either increased or maintained their IR&D expenditures and intensity in recent years in Canada. Some of these industries reflect Canada's traditional comparative advantage in natural resources, such as oil and gas extraction and pulp and paper manufacturing. The dominant source of competitive advantage for these industries is not development of new technologies. Rather, it comes from the rapid adoption of new ideas and technologies, which is facilitated by IR&D investment in these industries.

IR&D in Canada is relatively personnel intensive and less capital intensive when compared to other countries. Although Canada's rank by IR&D intensity is low among OECD countries, the share of the population employed in IR&D places Canada in the middle of the pack. Implicitly, the labour costs of Canadian IR&D personnel are low in comparison to other countries. Expenditures on capital equipment to perform IR&D are also proportionately lower. The full implication of these findings is unclear and warrants further study.

Fewer large firms undertake IR&D in Canada than in highly IR&D-intensive countries. The average size of firms performing IR&D in Canada is smaller than in other countries, and the share of total IR&D performed by smaller firms has increased. The relationship between IR&D expenditures and firm size is complex: IR&D intensity tends to be lower in larger firms, but larger firms are more likely to perform IR&D. Although it may be encouraging that smaller firms are undertaking relatively more IR&D, this could be holding back Canada's overall IR&D performance. There are economies of scale in IR&D, and larger firms may be needed to take the successes of smaller firms to a broader market.

Canada has the 12th highest rate of patents granted in the world, and the impact of Canadian patents is relatively high. Canada is responsible for 1.1 per cent of patents filed in Europe, Japan, and the United States, and around 4 per cent of the world's scientific journal articles. Canada also accounts for a relatively large share of world patents in pharmaceuticals and medicines (drugs), and communications technologies. Canadian industry patents are cited in other patents about 20 per cent more than the world average, suggesting a relatively high impact on development of related technologies.

Canadian firms report relatively high levels of innovation compared to firms in other countries. According to a series of innovation surveys in Canada and abroad, Canadian firms repeatedly report relatively high levels of innovation in contrast to their relatively low expenditures on IR&D. This suggests that Canadian firms do not rely on IR&D to generate innovation as much as firms in other countries. Innovation comes from other sources such as organizational change. It is less clear that Canadian firms perform as well in translating innovation into additional sales.

CANADA'S IR&D STRENGTHS

The Panel identified four industries of IR&D strength:

- Aerospace products and parts manufacturing
- Information and communication technologies (ICT)
- Oil and gas extraction
- Pharmaceutical and medicine manufacturing

These industries demonstrate strength by multiple measures, including those of magnitude and intensity, quality and impact, and trends. They all account for a substantial share of total Canadian IR&D, and have high levels of impact on at least one of the key IR&D outputs (patents or publications). There are, however, important differences both within and across these industries. Not all ICT industries show similar patterns of strength. Some, such as computer systems design and related services, show strength across nearly all measures. Others, such as communications equipment manufacturing, have high levels of impact on patents and publications, but have experienced declining IR&D expenditures and economic output in recent years. The aerospace industry accounts for a large share of world aerospace exports; however, the impact of its IR&D, based on patent and publication citations, is only average. The oil and gas industry has a high level of impact based on patent citations and rapid growth in both IR&D expenditures and economic output. While the pharmaceutical industry also shows strength by several measures of magnitude and impact, its IR&D expenditures have declined over the past decade.

The resulting picture of IR&D activity in Canada is complex and multifaceted, underlining the inherent multidimensionality of the concept of IR&D strength.

REGIONAL DISTRIBUTION OF IR&D ACTIVITY AND STRENGTH

Firms locating their IR&D facilities in close proximity can be a powerful driver of IR&D as neighbouring firms learn from and compete with each other. To assess the regional distribution of IR&D strengths in Canada, the Panel examined the provincial distribution of IR&D strength and activity. Based on these data, IR&D activities across all industries tend to concentrate in Ontario and Quebec. Across the four industries of IR&D strength identified by the Panel, these two provinces accounted for roughly three-quarters of total IR&D expenditures. Nonetheless, the distribution of IR&D activity in these industries varies considerably:

- *Aerospace*: Around three-quarters of all IR&D takes place in Quebec, and most of the remainder in Ontario.
- *ICT*: IR&D for almost all industries is most heavily concentrated in Ontario, with Quebec accounting for the highest share of computer and electronic product manufacturing. British Columbia also has a relatively high share of IR&D, particularly in computer and peripheral manufacturing, semiconductors, and computer system design and related services.
- *Oil and gas*: The regional distribution of IR&D is unclear due in part to data suppression to protect firm anonymity. The distribution of patenting activity, however, shows that the majority of IR&D most likely occurs in Alberta, with a substantial share in British Columbia.
- *Pharmaceuticals*: IR&D activities are distributed mainly across Ontario and Quebec, with British Columbia accounting for most of the remainder.

ALIGNMENT OF IR&D WITH CANADA'S S&T AND ECONOMIC STRENGTHS

The Panel found limited alignment between Canada's areas of science and technology (S&T) strength, IR&D strength, and overall economic strength. The Panel used the six research fields identified in the Council's 2012 State of S&T in Canada report as areas of S&T strength. The Panel then explored three measures that best capture economic strength at the aggregate level: industry growth, industry domestic size, and OECD relative size.

Figure 1 presents Canada's S&T strengths, IR&D strengths, and the industries that account for relatively large shares of the Canadian economy. There are some areas of congruence. Canada's research strength related to clinical medicine may be a contributor to the strength of the pharmaceutical and medicine manufacturing industry. Likewise, Canada's research strength in ICT is likely related to IR&D in the ICT sector. Canada's IR&D strengths related to the aerospace and oil and gas industries also directly map to areas where the Canadian economy shows a

relatively high level of specialization (i.e., aircraft and spacecraft manufacturing and mining and quarrying, which in this case includes oil and gas). These relationships are plausible and suggest connections are being made between Canada's S&T strengths, IR&D activities, and industries of particular economic importance to Canada. More research, however, is required to further validate, document, and explore these relationships.

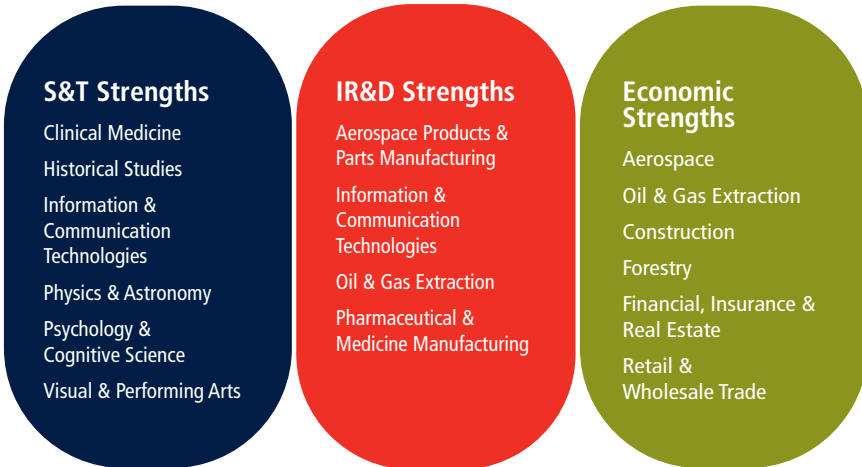


Figure 1
Alignment of Canadian S&T, IR&D, and Economic Strengths

A limited congruence between S&T, IR&D, and economic strengths is in part to be expected because of the inherently complex, dynamic, and non-linear nature of these relationships, and the different incentives for production of knowledge in different spheres. These interactions take place within a system in which all the drivers must be strong.

One of the critical components of an effective system is strong demand for innovative products. Not only must there be a plentiful supply of skilled workers and ideas from higher education, but demand for these critical inputs must also be strong. It is often suggested that insufficient competitive intensity in the Canadian economy limits demand for innovation, and in turn for IR&D. Firms invest less in IR&D without the imperative to develop new products and lower costs to survive and prosper, or to use new technologies to improve their competitiveness.

The Panel also identified five barriers to translation of S&T knowledge into innovation and wealth creation advanced by the academic and public policy literature:

- *Technology transfer*: Low rates of growth in patents and licensing agreements at Canadian higher education institutions, relative to new investments in research and technology transfer personnel, suggest existing technology transfer processes are not effective.
- *Managerial expertise*: Evidence suggests that Canadian managers have lower levels of education than their counterparts in the United States; and that managerial, commercialization, and organizational skills may be partially responsible for Canada's record of comparatively low productivity growth.
- *Business support*: New ventures in Canada receive relatively little direct public funding support for development and commercialization of new technologies. Unlike other countries, the majority of public support for IR&D in Canada is provided through tax credits, rather than direct investment.
- *Public procurement*: Relatively few demand-side policies in Canada encourage IR&D by creating markets for new technologies, products, or services.
- *Business culture*: Canadian business leaders are risk averse relative to their U.S. counterparts. As a result, Canadian firms may be less likely to take on the risks associated with translating new research discoveries into commercial products and/or using new technologies.

CHALLENGES OF IR&D DATA AND INDUSTRY CLASSIFICATION PRACTICES

The Panel encountered significant challenges in the way that data on IR&D expenditures (and other variables) are assigned to specific industries in Canada. IR&D expenditures are currently assigned according to the principal activity of an industry rather than to the industries served by the IR&D. Although conforming to the OECD's *Frascati Manual*, this practice made it difficult for the Panel to obtain the desired level of detail and precision in its assessment of the Canadian IR&D landscape.

The Panel questioned whether the available data underestimate the amount of IR&D undertaken in support of certain manufacturing industries. Since manufacturing increasingly takes place elsewhere in the world, IR&D is often assigned to the wholesale trade services industry because only marketing and IR&D activities remain in Canada. For example, IR&D aimed at developing new drugs may be assigned to the scientific research and development or wholesale trade industries, rather than to the pharmaceutical manufacturing industry.

Since 2004, the United States has adjusted its data manually to address this issue. This change has resulted in a large shift of IR&D expenditures out of wholesale trade and into highly IR&D-intensive industries such as pharmaceuticals and information and communication technologies. Some European statistical agencies also require that firms specify for which product(s) the IR&D is being conducted.

FINAL REFLECTIONS

When judged by many of the traditional indicators, Canada's overall IR&D performance is relatively weak. Canada, however, has substantial IR&D strength in several key industries. In addition, there may be many other niche areas of Canadian excellence and technological development. Nothing precludes Canadian researchers and businesses from making advances and contributions across all industries (or all scientific domains). A single, small firm can have a large impact on a globally dispersed industry with the introduction of the right technology at the right time.

Inevitably, the future commercial successes or failures in many industries will hinge on the extent to which Canadian firms are capable of adopting, developing, and marketing world-leading technologies. Building a strong foundation of IR&D is an essential part of developing that capacity for the future, thereby ensuring that Canadian firms can successfully compete in a global economy increasingly centred on knowledge and technology.

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DEFINITIONS OF KEY TERMS

For the purposes of this report, the Panel was guided by the following definitions:

Research and Development (R&D):

The Panel adopted the definition of R&D from the OECD's *Frascati Manual*: "Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OECD, 2002).

Industrial R&D (IR&D):

Industrial R&D is R&D undertaken by industry. As such, *expenditures* on IR&D should be regarded as synonymous with business enterprise expenditure on R&D (BERD) as collected and reported by the OECD.

Innovation:

The Panel defined innovation as the creation of "new or better ways of doing valued things," following CCA (2009). Where appropriate, the Panel also drew on the *Oslo Manual* definition of innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD/Eurostat, 2005).

Science and Technology (S&T):

The Panel also relied on the definition of S&T provided by the Council's previous assessments on the State of Science and Technology in Canada. According to this definition, S&T "encompasses disciplines in the natural sciences (the study of nature); the social sciences, humanities, and health sciences (the study of human beings); and engineering (the creation and study of artifacts and systems)," and includes consideration of the "myriad connections from science to technology and vice versa" (CCA, 2006, 2012a).

Sector versus Industry:

The Panel followed the convention of referring to a collection of related industries as a sector (e.g., the manufacturing sector, which would include the semiconductor industry and the automotive industry).

1

Introduction

- **Benefits of IR&D**
- **Canada's Recent Economic Performance**
- **Charge to the Panel**
- **Approach and Methodology**
- **Structure of the Report**

1 Introduction

Industrial research and development (IR&D) consists of any scientific research or technology development undertaken by, or at the direction of, businesses. It can lead to development of products that revolutionize the way we live our lives. IR&D benefits those who consume and use the products developed, the firms that invest in IR&D, and the economy at large. At the same time, IR&D can fundamentally advance scientific knowledge of the world.

New products and ideas are the essence of innovation that increases the value of goods and services produced by firms. While innovation is, and needs to be, much broader than IR&D, IR&D is clearly a driver of innovation. In turn, increasing the value of output per hour worked (i.e., productivity) is one of the core drivers of economic growth, and by far the most important in the long run (for a review, see CCA, 2009; Hall & Jones, 1999; Jones & Romer, 2010).

For most of the 20th century, and now into the 21st, Canadian policy-makers have attempted to craft policies to better promote IR&D and innovation in Canadian businesses. The Senate Special Committee on Science Policy (1970) reported that “Since 1916 [...] the main objective of Canadian science policy has been to promote technological innovation by industry. [...] Almost every decade since the 1920s has witnessed renewed attempts by successive governments to achieve it but, on the whole, they have all failed.” Canada’s IR&D intensity remains relatively low by international standards. Given the potential of IR&D to boost economic growth, its relatively low intensity can help explain Canada’s persistent productivity gap with the United States (CCA, 2009).

Many innovation researchers in Canada have suggested that some of the past research on IR&D has been too focused on nationally aggregated statistics, making it not sufficiently specific to the unique context and market prospects of any particular industry (Hawkins, 2012). Previous analyses may also have failed to adequately differentiate between emerging and mature markets (Miller & Côté, 2012), or were dominated by an overly narrow focus on high-technology industries (Naylor, 2012). As a result, there is a growing interest in Canada in building a more nuanced understanding of IR&D performance that takes into account differences across industries.

1.1 BENEFITS OF IR&D

The economic benefits of improved IR&D performance can be substantial. Consumers benefit by gaining access to novel goods or services that exploit cutting-edge technologies. Firms gain a competitive advantage by introducing new products or adopting new work processes. IR&D can help overcome global challenges by developing low-emission sources of energy or improving the quality of life in an older population. In short, the roles of IR&D can range from increasing consumer satisfaction today to addressing the most pressing global issues facing society tomorrow.

The generation of novel ideas from research, and their development into products in demand by the market, creates a competitive advantage for firms. Profits generated from IR&D enhance a firm's commercial position and ensure its long-term survival and success. New or improved production processes developed through IR&D can increase the power of computer chips, enhance the efficiency of extracting natural resources, and/or lower production costs. Given the commercial potential of products and ideas derived from IR&D, firms have many incentives to invest in it, particularly in those industries (e.g., pharmaceuticals) whose lifeblood is scientifically advanced products. In some industries, such as those linked to semiconductors, technological change is so rapid that firms must invest in IR&D simply to keep up with the changes in the marketplace and survive.

Investment in IR&D is strengthened as the degree of competition in an economy increases. Competition creates the imperative to develop new products and lower costs. IR&D is strong in many small economies because they are open to world markets, and, to compete globally, their firms must invest in IR&D. Empirical research suggests that innovation increases with the degree of competition (e.g., Blundell *et al.*, 1999; Aghion *et al.*, 2005).

The benefits of a firm's R&D also accrue to the economy at large. For example, the logistics industry has been transformed by innovations such as just-in-time inventory systems facilitated by advances in computers and software developed from IR&D. Many retailers have drastically restructured their inventory controls as a result, which has led to dramatic improvements in their effectiveness (Triplett & Bosworth, 2004). In turn, these improvements have resulted in reduced operating costs and increased profitability, benefitting the economy as a whole.

The positive impact of IR&D can spread widely. As soon as a new product is made public or a patent or scientific article is published, the knowledge enters the public domain, leaving others free to explore related opportunities. A fresh

pair of eyes can develop new applications, or use the innovation to solve other problems. Such openness is the cornerstone of further IR&D and innovation, and hence economic growth (Romer, 1990; Jones, 2005).

Canada not only benefits from IR&D undertaken in Canada but also from IR&D investments elsewhere in the world. Advances in knowledge can often cross borders with little cost as new ideas are announced in publications or at conferences. To fully benefit from ideas produced elsewhere, however, a country typically needs to rely on its own pool of skilled researchers capable of understanding and adapting these innovations to local circumstances and needs. Acquiring and applying the results of IR&D produced elsewhere requires effort by the recipient firm (Cohen & Levinthal, 1989). Firms' investment in this "absorptive capacity" of IR&D has been found to be a key advantage of strengthening domestic IR&D (Girma, 2005; Bibbee, 2012; for pharmaceuticals, see Wakelin, 1998, and Cockburn & Henderson, 1998). Canada cannot rely on simply importing the latest innovations from abroad. Getting the most out of global innovations requires that the absorptive capacity created by undertaking IR&D exists within Canada.

For all these reasons, IR&D promotes innovation in an economy. Innovation is the implementation of new or significantly improved goods and services, or the provision of existing goods through improved business practices that enhance productivity, profitability, and performance. As such, innovation is much broader than IR&D. But, because IR&D is a source of many new ideas and products, it is a particularly potent contributor to innovation. Innovation, in turn, is a key driver of productivity growth. Productivity is the output generated for each hour worked. It comes from working smarter and more efficiently, and not from working more hours. Productivity can be strengthened through improving the skills and education of Canadians, investing in more efficient capital equipment, and, fundamentally, by innovating.

Innovation is particularly critical to advancing productivity for countries, such as Canada, that are at the leading edge of technology. At this "technological frontier," the only way to advance technologically is through innovation since the best technologies are already in use. Developing countries far from the frontier can progress rapidly to catch up with developed economies by mimicking their technology investments and product development strategies. Such imitation, however, only allows an economy to reach the technological frontier, and not to advance it. Countries at the leading edge of technology must push the technology frontier to maintain or improve their global competitiveness. This requires internal

absorptive capacity to understand and apply new global innovations, as well as core strength in fundamental innovation, primarily from IR&D (Acemoglu *et al.*, 2006; Aghion & Howitt, 2006).

While IR&D contributes to innovation, it can also promote other elements of productivity. For example, the output of IR&D is often embodied in novel machinery and equipment, which improve business performance as firms produce more and better output. Acquiring modern machinery and equipment also provides firms with the opportunity for further innovation by supporting the reorganization of workplaces and industrial processes. By impacting the economy through all these different channels, economic research suggests that the benefits to the overall economy from IR&D are substantial.

Economists have been examining the rate of return on IR&D for decades. The overwhelming consensus is that the returns are substantial. In particular, the returns to the economy as a whole substantially exceed the returns to an individual firm (Griliches, 1980, 1992; Hall *et al.*, 2010). Generally, the rate of return to a private firm is of the order of 10 to 20 per cent (Hall *et al.*, 2010). Conventional estimates of the rate of return to the entire economy can reach up to twice as high (Bernstein & Nadiri, 1988), or even higher in a dynamic framework (Jones & Williams, 1998). Countries further from the technological frontier will benefit more than their technologically advanced counterparts. Griffith *et al.* (2003) suggest the return on IR&D could be as high as 60 per cent in Canada. Approaches to measuring the returns to investment in innovation more broadly are discussed in a recent Council of Canadian Academies report (CCA, 2013).

1.2 CANADA'S RECENT ECONOMIC PERFORMANCE

Notwithstanding the recent global recession and high unemployment rates in many countries, Canada has improved living standards over the past decade without being a global leader in IR&D or productivity (OECD, 2012a; CCA, 2009). A country's living standards can rise if the employment rate (the share of the working-age population who are employed) and/or productivity of its workforce, and/or the prices for its exported goods and services, increase (e.g., see Macdonald, 2011).

In recent years, higher employment rates and rising prices for exports have driven Canada's economic growth, despite low labour productivity. Since 2000, Canada's job creation record has been among the best in the Organisation for Economic Co-operation and Development (OECD). A greater share of the population is now at work in Canada than in most other countries. Canada has also benefitted from

improved terms of trade (the prices of exports relative to imports). The growth in demand for natural resources from rapidly industrializing developing economies, such as China and India, has led to higher market prices for most of Canada's exports. In contrast, Canada ranked 31st of 38 OECD economies in productivity performance since 2000.¹

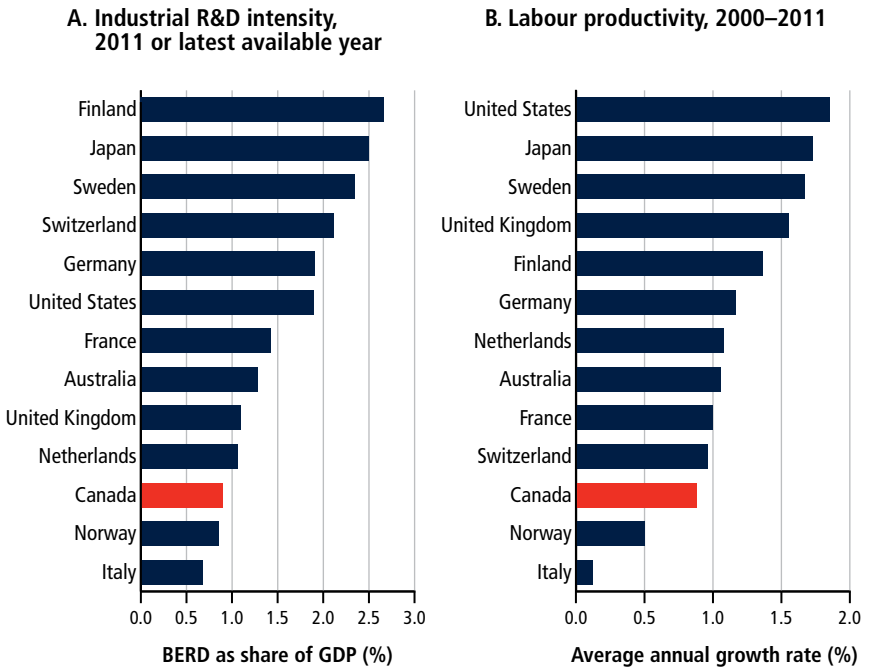
Going forward, Canada cannot rely on job growth and improved terms of trade to drive continued improvement in living standards. Population aging means that employment growth will weaken as the share of the population of working age inexorably declines.² Canada faces more rapid population aging than many other OECD economies (OECD, 2008a). Uncertainties in the global economy also make continued reliance on improving terms of trade a source of volatility in the domestic economy. Although prices in the global economy are set by patterns of global demand, the productivity of the Canadian economy is well within Canadian control.

By improving productivity, IR&D has the potential to be a core building block of Canada's future prosperity. Despite significant expenditures on R&D by government and higher education institutions, in 2009 Canada ranked 18th out of 34 OECD countries in the proportion of economic resources spent on IR&D (OECD, 2013). Notably, Canada's expenditures on IR&D are less than half the rate of economies such as Sweden and Finland (see Figure 1.1). The link between increased investment in IR&D and better productivity performance is not automatic.³ During the 1990s, labour productivity growth in Canada only managed to keep pace with the United States despite the IR&D gap closing. However, Canada's productivity growth over the 2000–2011 period lagged behind leading countries, coinciding with weak levels of IR&D intensity (see Figure 1.1). As the role of innovation becomes even more important in a globalizing economy, the contribution of IR&D to productivity becomes more central to improving living standards. Certainly in Canada, increasing labour productivity is critical to improving living standards. As Paul Krugman (1990) noted, “productivity isn't everything, but in the long-run it is almost everything.”

1 OECD rankings in this section are calculated based on the number of countries for which data are available. For example, data on R&D expenditures by country are not available for all countries for all years. Average annual growth in labour productivity for OECD countries was 1.5 per cent for 2000–2011, and 0.9 per cent for Canada based on the Panel's analysis of OECD (2012c).

2 For a review of the impacts of aging on productivity, see Beach (2008). See OCA (2011) for demographic projections outlined by Canada's Chief Actuary, which forecast that immigration is unlikely to materially reduce the impacts of aging unless the level of immigration significantly increases and the average age at immigration falls.

3 Another means of improving productivity is machinery and equipment investment, which often embodies the latest IR&D (ab Iorwerth, 2005a). The latest evidence, presented by Diewert and Yu (2012), suggests that Canada's rate of physical investment is also lagging.



IR&D intensity is business enterprise expenditure on R&D (BERD) as a share of gross domestic product (GDP).

Growth rates are annual averages.

Data source: OECD (2013) and Panel calculations based on OECD (2012c)

Figure 1.1

IR&D Intensity and Growth in Labour Productivity, Selected OECD Economies

Canada's IR&D intensity and productivity growth lag behind those of leading industrial economies. Although the link between improved IR&D and productivity performance is not automatic, countries with higher productivity growth tend to invest more in IR&D.

1.3 CHARGE TO THE PANEL

In 2011 the Minister of Industry, on behalf of Industry Canada, asked the Council of Canadian Academies (the Council) to undertake a comprehensive assessment of the state of science and technology in Canada to update and build on its 2006 report (CCA, 2006). In response, the Council formed two expert panels. The Expert Panel on the State of S&T in Canada focused on Canada's S&T strengths primarily as embodied in the R&D efforts of Canadian universities, colleges, and polytechnics (the higher education sector) (CCA, 2012a). This report presents the findings of the Expert Panel on the State of Industrial R&D in Canada (the Panel), which has focused on R&D activities and strengths in Canadian industry.

Specifically, the charge to the Panel was as follows:

What is the current state of industrial research and development (IR&D) in Canada?

Three sub-questions were included in the Panel's charge:

What are Canada's industrial R&D strengths? How are these strengths distributed by sector and geographically across the country? How do these trends compare with what has been taking place in comparable countries?

In which scientific disciplines and technological applications are our relative strengths most aligned with Canada's economic strengths/industry needs?

What are the key barriers and knowledge gaps in translating Canadian strengths in S&T into innovation and wealth creation?

The Panel was made up of 14 experts with a diverse range of professional experience, drawn from the energy, finance, aerospace, forestry, mining, information and communication technologies, and biotechnology industries. Some Panel Members had experience in the higher education sector, a broad knowledge of Canada's science and technology landscape, or were economists with expertise in the study of R&D. The Panel met five times over the course of 2012 and early 2013 to review evidence, deliberate, and formulate its findings.

Because academic research and IR&D are inter-related, the analysis and deliberations of the Panel (and the Expert Panel on S&T) carefully considered the complex relationship between the higher education sector and industry in Canada. The focus of this assessment, however, is R&D activity performed by industry. R&D activities undertaken in higher education or government research facilities are excluded from the scope of this study.

1.4 APPROACH AND METHODOLOGY

The Panel reviewed and evaluated many types of evidence. It examined the relevant published literature, including a survey of studies in academic and scientific journals; government and OECD reports and databases; and studies from think-tanks, non-profits, and other organizations. The Panel also commissioned original research in the form of a study of patenting and publication patterns of Canadian firms (conducted by Science-Metrix). This is the first Canadian study to analyze patterns in scientific publication and intellectual property generation

at a detailed and industry-specific level. Chapter 4 presents the results of the analysis, and Appendix A describes the methodology used in the collection and analysis of the data.

In its examination of the available evidence and consideration of the implications for IR&D performance and strength, the Panel followed five general guidelines to ensure a comprehensive and balanced analysis:

- examine both output and input indicators;
- compare Canada's performance to other countries;
- analyze each industry in turn;
- stress both quality and quantity; and
- consider long-term trends.

1.4.1 Organization by Indicator Type

The Panel organized its assessment of IR&D in Canada by three general types of indicators: IR&D *inputs*, IR&D *outputs*, and IR&D *outcomes*.

Indicators of IR&D Inputs: Most of the available evidence to assess IR&D performance across industries and countries relates to inputs. The Panel analyzed measures of IR&D expenditures and personnel, using both cross-country and cross-industry comparisons wherever possible. The Panel also looked at IR&D intensity, which is the ratio of IR&D expenditures to value added.⁴ Unfortunately, the most recent internationally comparable data available on IR&D intensity were often five or more years out of date.

Indicators of IR&D Outputs: Despite the more limited data available on relevant IR&D outputs, the Panel examined two measures in detail: patents and scientific publications. Although not without limitations, these indicators allow for systematic comparison of patenting and publication activities across industries, as well as analysis of the impact of Canadian R&D in specific industries as reflected by patent and publication citations. These two measures admittedly cover only a small part of the full spectrum of outputs associated with IR&D. In many cases, IR&D may lead directly to new products, processes, or services in the absence of such outputs.

Indicators of IR&D Outcomes: Causally connecting specific outcomes directly to IR&D activities is difficult. Although IR&D is not synonymous with innovation, arguably all IR&D is undertaken with the aim of fostering some form of innovation.

4 Value added is the difference between the value of goods sold and the cost of material inputs. It generally captures total labour expense and operating profit before depreciation.

Thus the Panel analyzed two measures of innovation at the industry level: differences in the propensity to innovate across sectors (and countries) as recorded in innovation surveys, and changes in Canada's relative performance in labour productivity over time.⁵ The Panel also examined several other expert opinion surveys that capture information about Canada's reputation in particular industries or technologies, and Canada's share of world exports in high-technology industries, though the data are more limited and indirect.

1.4.2 Challenges of Industry Classification Practices

Business activities are assigned to industries according to the North American Industry Classification System (NAICS).⁶ The Panel encountered significant challenges associated with how data on IR&D expenditures (and other variables) are assigned to an industry in Canada. First, R&D expenditures are classified by industry according to the principal activity of that industry. This can lead to confusing results, particularly in the wholesale trade and scientific research and development services industries. For example, IR&D in pharmaceuticals may be assigned to the pharmaceutical manufacturing industry, the wholesale trade service industry, or the scientific research and development services industry, depending on the balance of the firm's activities. Canada, however, is not alone in facing this issue. Efforts to correct for this issue in the United States resulted in a large shift of IR&D expenditures out of wholesale trade and into highly IR&D-intensive industries such as pharmaceuticals and information and communication technologies.

Second, the scientific research and development services industry classification gives little indication of the type of IR&D effort undertaken or its commercial applications. Many of the IR&D expenditures assigned here are likely associated with industry-supported R&D centres tied to many different industries. In addition, Statistics Canada's analysis suggests that pre-commercial start-ups of many kinds may be assigned to this industry class in the absence of a marketable product (Lonmo, 2007). Without more detailed data, it is impossible to ascertain the types of IR&D classified as scientific research and development services. A detailed discussion of these challenges is included in Appendix B.

5 To a degree, multifactor productivity more closely approximates innovation as labour productivity also includes the impact of investment in physical and human capital. However, it is more difficult to compare levels and growth rates of multifactor productivity across countries given debates about methodologies.

6 ISIC (International Standard Industrial Classification) classifications are also used in some cases for the purposes of international comparison.

1.5 STRUCTURE OF THE REPORT

Chapters 2 through 5 review the available empirical evidence relevant to this assessment, relying on publicly available statistics from organizations such as the OECD and Statistics Canada, as well as original data collected by the Panel. Where allowed by the data, the chapters include international comparisons and review relevant trends over the last decade.

Chapter 6 synthesizes all of the available evidence to identify Canada's areas of IR&D strength, as well as the distribution of those strengths across the country. Turning to a different aspect of the Panel's charge, Chapter 7 discusses to what extent Canada's IR&D strengths are currently aligned with Canada's S&T and economic strengths. This chapter also surveys and analyzes the evidence related to barriers and gaps that limit translation of Canada's S&T strengths into innovation and wealth creation. Chapter 8 summarizes the Panel's main findings in response to each of the questions in the charge.

Appendix A outlines the methodology used in collection and analysis of the publication and patent data discussed in Chapter 4. And Appendix B describes some of the technical issues and limitations associated with different industry classification systems.

2

Industrial R&D Inputs: Expenditures and Personnel

- **International Comparisons of IR&D Expenditures**
- **R&D Expenditures and Personnel in Canada by Industry**
- **International Comparisons of R&D Intensity by Industry**
- **Understanding Canada's Low IR&D Intensity**
- **International Comparisons of IR&D Personnel and Capital**
- **Distribution of BERD by Firm Size in Canada**
- **Conclusion**

2 Industrial R&D Inputs: Expenditures and Personnel

Key Findings

- The Canadian business sector invests relatively little in R&D compared to peers abroad although some industries are highly R&D intensive by international standards.
- In common with other advanced economies, IR&D expenditures and personnel in Canada are concentrated in a number of traditionally R&D-intensive industries such as scientific research and development services, aerospace, and information and communication technologies. Six industries collectively account for over half of all R&D spending in Canada.
- Canada's investment in IR&D remains low by international standards even when the overall structure of the Canadian economy is taken into account. The relatively large share of the Canadian economy accounted for by natural resource industries has almost no impact on the IR&D intensity gap between Canada and the United States. Rather, the relatively low IR&D intensity in the Canadian manufacturing sector is more important.
- The IR&D intensity of Canada's high-technology manufacturing industries is comparable with that of other countries. These industries, however, form a smaller share of the economy in Canada. This smaller size drags down the manufacturing sector's aggregate IR&D intensity.
- While a relatively high degree of foreign ownership may act to lower R&D in some industries, it is unlikely that this fully explains the overall picture in Canada.
- Many industries that traditionally do not spend as much on R&D have either increased or maintained their R&D expenditures and intensity in recent years in Canada.
- IR&D in Canada is relatively personnel intensive and relatively less capital intensive when compared to other countries.
- Fewer large firms undertake R&D in Canada than in highly IR&D-intensive countries.

Much of the analysis traditionally undertaken of IR&D has focused on expenditures, which are inputs to the IR&D process. Although they cannot be used in isolation to identify IR&D success or strength (see Box 2.1), an analysis of expenditures is useful in two respects. First, IR&D expenditures can be valuable benchmarks of the degree to which a firm, industry, or country is investing resources in support of IR&D efforts. Since IR&D expenditures are controlled by firms, they also give insights into firm decision-making. Second, expenditure data indicate where IR&D activity is taking place, showing the distribution of IR&D across industries, regions, or countries. Data on IR&D personnel can provide a complementary perspective to that of expenditures.

IR&D expenditures can be analyzed by absolute levels across industries and by intensities (i.e., the level of IR&D expenditures in proportion to sales or value added). Examining IR&D intensities facilitates comparisons across countries and yields insights into business performance over time. For example, although an industry may shrink through moving production offshore, it may become more IR&D intensive if it retains its core IR&D related to product development in Canada.

In addition to a detailed review and analysis of industry and international data on IR&D expenditures and personnel, the Panel also examined several factors that could account for Canada's relatively low IR&D intensity in comparison to peer countries.

2.1 INTERNATIONAL COMPARISONS OF IR&D EXPENDITURES

Overall, the Canadian business sector does not invest as much in IR&D relative to other countries. This well-established fact has been analyzed and discussed in many previous reports and publications on the Canadian science, technology, and innovation landscape (e.g., CCA, 2006, 2009, 2012a; STIC, 2009, 2011; Industry Canada, 2011a; AUCC, 2008). The latest data collected by the OECD do not suggest any change to this pattern in recent years. In absolute terms, Canada's overall level of investment in IR&D (as reflected by IR&D expenditures undertaken in the business sector) is nonetheless substantial. Canada ranks 11th among the countries for which the OECD collects data in terms of the absolute size of spending on IR&D (see Table 2.1). According to the OECD, Canada was the 12th largest economy in 2010, based on a comparison of economic sizes and taking differences in price levels into account (OECD, 2013).

When IR&D expenditures are considered in relation to the size of a country's economy, however, Canada compares poorly with its international peers. Canada's ratio of BERD to GDP now stands below one per cent (Table 2.1). In comparison, the business sector in the United States invests over two per cent of GDP in IR&D, and the average BERD to GDP ratio for the OECD is 1.6 per cent.

Box 2.1**IR&D Expenditures and Innovation: The Case of Apple Inc.**

In 2010 a Booz & Co. survey asked over 600 executives from 400 leading global firms to identify the “most innovative” firms in the world. The winner of the poll, for the second year running, was Apple Inc. for its impressive record of innovative new products. The survey result is puzzling in one respect. Apple’s reputation for innovation could be perceived as disproportionate to its level of investment in R&D. In the same survey, Apple ranked 81st in total R&D spending, and its R&D intensity (R&D expenditures relative to revenue) was only 3.1 per cent. In comparison, both Google and Microsoft invested over 10 per cent of revenues in R&D. Of the top 10 most innovative firms, only 3 were also in the list of top 10 R&D spenders in the survey (Booz & Co., 2011). Apple’s successful record of innovation was clearly not a function of R&D spending alone. It was also related to investments in innovation in its supply chain, marketing, and design.

It is tempting to think of investments in IR&D as having a guaranteed rate of return, both at the firm and national levels. At the firm level, however, managers are well aware that R&D expenditures are a means to an end. In and of themselves, they represent a cost centre rather than a measure of success, and that outcome is never guaranteed. When faced with the challenges of measuring such intangibles as innovation, metrics based on IR&D expenditures are frequently adopted at the industry and national levels simply because they are one of the few available (and quantifiable) data points. It is important to remember, however, that IR&D expenditures are only a partial measure of innovation.

2.2 R&D EXPENDITURES AND PERSONNEL IN CANADA BY INDUSTRY

In total, Canadian businesses invested around \$15.5 billion in IR&D in 2012, below the peak of \$16.8 billion in 2007 (Statistics Canada, 2012b). Six industries each invested over one billion dollars in IR&D in 2011, accounting for over half of all IR&D expenditures: scientific research and development services, communications equipment manufacturing, wholesale trade, aerospace products and parts manufacturing, computer systems design and related services, and information and cultural industries (see Table 2.2).

The distribution of IR&D personnel levels presents a similar picture to the expenditure pattern because expenditures on wages and salaries account for nearly two-thirds of total IR&D spending in Canada (Statistics Canada, 2012b). R&D personnel include researchers, technicians, and support staff.⁷

Table 2.1
BERD for Top 20 Countries, 2011 or Latest Available Year

		BERD	
		US\$ (in millions)	Share of GDP (%)
1	United States	250,365	1.89
2	China	117,837	1.29
3	Japan	98,383	2.49
4	Germany	53,822	1.90
5	Korea	36,987	2.80
6	France	27,849	1.43
7	United Kingdom	22,449	1.09
8	Chinese Taipei	15,416	2.08
9	Russian Federation	14,339	0.68
10	Italy	11,143	0.68
11	Canada	10,986	0.89
12	Australia	10,425	1.28
13	Spain	8,656	0.70
14	Sweden	7,760	2.34
15	Israel	7,343	3.51
16	Netherlands	6,604	1.07
17	Switzerland	6,384	2.11
18	Austria	5,693	1.87
19	Belgium	5,001	1.37
20	Finland	4,599	2.67

The level of expenditures is in constant 2005 U.S. dollars adjusted for purchasing power parity (PPP).
Countries ranked by total expenditure.

Data source: OECD (2013)

The table presents data on BERD and BERD as a share of the country's GDP. In absolute terms, Canada invests a large amount in IR&D. However, in proportion to the size of its economy, Canada does not invest as much as other countries.

⁷ Statistics Canada (2012b) reports that 66 per cent of R&D personnel are professionals, 27 per cent are technicians, and 8 per cent are classified as "other." Statistics Canada (2012b) follows international conventions in defining professional personnel as researchers or R&D managers. They can be either scientists or engineers. Researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods, and systems, and also in the management of the projects concerned. Managers and administrators engaged in the planning and management of the scientific and technical aspects of a researcher's work also fall into this category.

Table 2.2
BERD and IR&D Personnel in Canada by Sector and Industry

	BERD, 2012	Share of total BERD	Average annual growth,	Number of IR&D personnel, 2010 (full-time equivalent)	Share of total number of researchers	Average annual growth,
	\$ millions	(%)	2000–2012 (%)		(%)	2000–2010 (%)
Total for all industries	15,493	100.0	1.9	136,203	100.0	2.7
Agriculture, forestry, fishing and hunting	123	0.8	2.7	1,744	1.3	8.0
Agriculture	99	0.6	5.7	1,467	1.1	10.8
Forestry, logging and support activities for forestry	14	0.1	-0.6	161	0.1	-0.8
Fishing, hunting, trapping and animal aquaculture	10	0.1	1.9	116	0.1	1.0
Mining and oil and gas extraction	732	4.7	12.3	1,821	1.3	9.6
Oil and gas extraction, contract drilling and related services	646	4.2	14.4	1,352	1.0	13.6
Mining and related support activities	99	0.6	5.8	469	0.3	2.9
Utilities	201	1.3	-2.3	1,436	1.1	4.0
Electric power generation, transmission and distribution	181	1.2	-3.0	997	0.7	1.5
Other utilities	21	0.1	11.0	338	0.2	9.9
Construction	101	0.7	7.5	1,711	1.3	8.9

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	BERD, 2012		Share of total BERD (%)	Average annual growth, 2000-2012 (%)	Number of IR&D personnel, 2010 (full-time equivalent)	Share of total number of researchers (%)	Average annual growth, 2000-2010 (%)
	\$ millions	(%)					
Manufacturing	7,565	48.8		-0.9	60,791	44.6	-0.1
Food manufacturing	152	1.0		6.2	2,090	1.5	7.5
Beverage and tobacco product manufacturing	13	0.1		-4.7	179	0.1	0.9
Textiles	38	0.2		-1.6	551	0.4	-0.9
Wood product manufacturing	85	0.5		6.1	752	0.6	3.6
Paper manufacturing	122	0.8		-5.1	813	0.6	-3.5
Printing and related support activities	43	0.3		9.4	902	0.7	11.6
Petroleum and coal product manufacturing	321	2.1		22.8	196	0.1	-1.1
Pharmaceutical and medicine manufacturing	643	4.2		-1.4	3,850	2.8	-0.4
Other chemicals	283	1.8		1.9	2,326	1.7	1.4
Plastic product manufacturing	116	0.7		4.4	1,659	1.2	6.5
Rubber product manufacturing	20	0.1		-0.9	260	0.2	-3.0
Non-metallic mineral product manufacturing	71	0.5		8.5	798	0.6	9.9
Primary metal (ferrous)	47	0.3		-1.3	339	0.2	0.1
Primary metal (non-ferrous)	163	1.1		1.3	751	0.6	-3.4
Fabricated metal product manufacturing	216	1.4		7.1	3,707	2.7	8.8

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	BERD, 2012		Share of total BERD		Average annual growth, 2000–2012		Number of IR&D personnel, 2010		Share of total number of researchers		Average annual growth, 2000–2010	
	\$ millions	(%)	(%)	(%)	(%)	(%)	(full-time equivalent)	(%)	(%)	(%)	(%)	
Machinery manufacturing	591	3.8	3.8	3.2	7,346	5.4	4.7					
Computer and peripheral equipment manufacturing	42	0.3	0.3	-12.4	549	0.4	-13.3					
Communications equipment manufacturing	1,529	9.9	9.9	-6.4	8,396	6.2	-6.1					
Semiconductor and other electronic component manufacturing	479	3.1	3.1	-4.4	4,411	3.2	-1.7					
Navigational, measuring, medical and control instrument manufacturing	375	2.4	2.4	0.3	4,848	3.6	-0.4					
Other computer and electronic products	15	0.1	0.1	-3.8	289	0.2	1.2					
Electrical equipment, appliance and component manufacturing	167	1.1	1.1	-1.9	1,987	1.5	-1.6					
Motor vehicle and parts	318	2.1	2.1	-2.1	2,771	2.0	-0.6					
Aerospace products and parts manufacturing	1,298	8.4	8.4	3.3	6,031	4.4	0.0					
All other transportation equipment	156	1.0	1.0	17.7	1,217	0.9	14.3					
Furniture and related product manufacturing	41	0.3	0.3	13.5	758	0.6	13.0					
Other manufacturing industries	233	1.5	1.5	5.7	3,018	2.2	7.9					

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	BERD, 2012		Share of total BERD		Average annual growth, 2000-2012		Number of IR&D personnel, 2010		Share of total number of researchers		Average annual growth, 2000-2010	
	\$ millions	(%)	(%)	(%)	(%)	(%)	(full-time equivalent)	(%)	(%)	(%)		
Services	6,770	43.7	5.8	50.6	5.5	68,941	50.6	5.5				
Wholesale trade	1,302	8.4	4.4	7.3	8.1	9,995	7.3	8.1				
Retail trade	59	0.4	7.1	0.8	6.6	1,069	0.8	6.6				
Transportation and warehousing	56	0.4	4.2	0.4	3.7	531	0.4	3.7				
Information and cultural industries	1,264	8.2	12.6	8.7	9.8	11,802	8.7	9.8				
Finance, insurance and real estate	250	1.6	4.8	1.4	4.3	1,967	1.4	4.3				
Architectural, engineering and related services	354	2.3	-1.4	3.6	-0.3	4,866	3.6	-0.3				
Computer systems design and related services	1,275	8.2	4.1	13.1	3.1	17,827	13.1	3.1				
Management, scientific and technical consulting services	82	0.5	2.2	0.9	0.7	1,258	0.9	0.7				
Scientific research and development services	1,731	11.2	13.1	9.9	12.3	13,425	9.9	12.3				
Health care and social assistance	86	0.6	-10.0	0.9	-7.8	1,293	0.9	-7.8				
All other services	313	2.0	4.5	3.6	7.3	4,908	3.6	7.3				

Latest available data for expenditure in mining are for 2011 and 2010 for petroleum and coal product manufacturing. IR&D personnel data for total utilities and electricity power generation, transmission and distribution are for 2009. Growth rates are calculated for the years 2000 to 2012 with adjustments for data availability. Full-time equivalent employment includes employment of part-time workers based on hours worked, as well as those in full-time employment. The grey shaded rows indicate sectors.

Data source: Statistics Canada (2012b) and Panel calculations

The table shows basic statistics for Canada on IR&D expenditures and the number of personnel employed in IR&D. The level and growth of investment and personnel employed differ markedly by industry.

2.3 INTERNATIONAL COMPARISONS OF R&D INTENSITY BY INDUSTRY

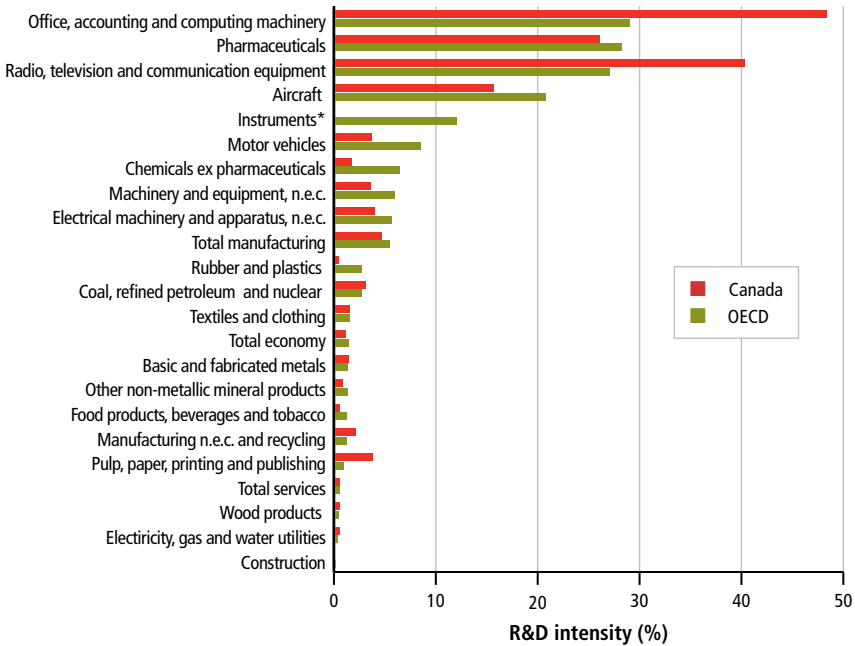
The scale of IR&D expenditures varies across industries. Some industries, such as pharmaceutical manufacturing and semiconductors, rely on internal IR&D to produce new and/or improved products and maintain their competitive advantage. Other industries, such as forestry products and oil and gas exploration, must purchase equipment that was an outcome of the IR&D of others. As a result, IR&D intensities, the ratio of IR&D expenditures to value added or sales, differ markedly across industries.

Analyzing IR&D intensities facilitates cross-country comparison since differences in country sizes are taken into account. It also makes more sense to compare the pulp and paper industry in Canada with the same industry in, say, Finland, than to compare it with semiconductor industries in Canada. High IR&D intensity in an industry in Canada as compared to other countries would suggest that the industry's competitive position is strong globally.⁸

Figure 2.1 shows the IR&D intensities of Canadian industries relative to the OECD average. Many of the most IR&D-intensive industries in Canada (as in most countries) are in the manufacturing sector, but, even within manufacturing, IR&D intensities vary significantly. Some service industries also have relatively high IR&D intensities. Although the overall IR&D intensity of the manufacturing sector in Canada is low, several industries show higher IR&D intensities in Canada than in other OECD countries. These include communications equipment manufacturing, office and computing machinery manufacturing, coke and refined petroleum products manufacturing, and pulp and paper.⁹ The IR&D intensity of Canadian pulp and paper, for example, is nearly double that of the pulp and paper industry in the United States. Industries with comparatively low IR&D intensities in Canada include food products, chemicals, rubber and plastics, motor vehicles, and construction.

8 R&D intensity is not sufficient to determine R&D strength and could be examined in connection with relative size and distribution of firm sizes. The theoretical basis for determining strength, however, is not *a priori* clear in those cases.

9 The OECD aggregates the pulp and paper industries, but Statistics Canada reports them separately.



R&D intensities are computed as a percentage of value added.
 n.e.c. is not elsewhere classified. *No data for Canada
 Data source: OECD (2012b)

Figure 2.1

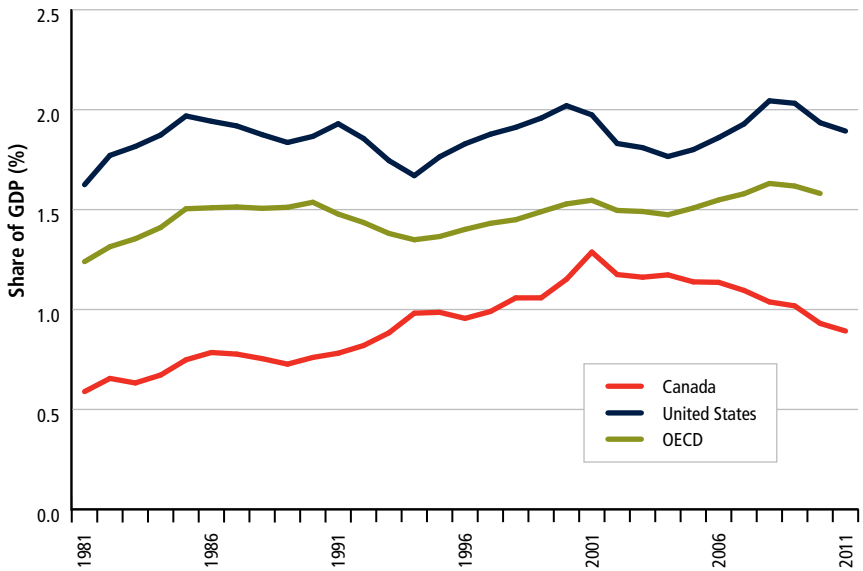
R&D Intensities by Industry, Canada and OECD Average, 2006

R&D intensities allow cross-country comparisons of investment in R&D by industry. Some R&D-intensive industries in other major economies also show very high degrees of IR&D intensity in Canada, such as office, accounting and computing machinery and radio, television and communications equipment. Other industries that do not traditionally invest as much in IR&D, such as pulp, paper, printing and publishing, are IR&D intensive in Canada compared to other countries. The motor vehicle manufacturing industry is IR&D intensive in other economies, but less so in Canada.

2.4 UNDERSTANDING CANADA'S LOW IR&D INTENSITY

The relatively low level of IR&D intensity appears to be a persistent feature of the Canadian economy. Despite closing in the years up to 2001, the gap between Canada and other countries has now widened (see Figure 2.2).¹⁰ Canada is one of very few countries with a negative average annual growth rate since 2000, declining by an annual average of 2.1 per cent in the 10 years since 2000. R&D intensity in the business sector fell from 1.2 per cent in 2000 to 0.9 per cent in 2011.

¹⁰ As discussed in Chapter 1, however, economic growth has also been stronger in Canada. Even if R&D investment was increasing at the same rate as that of other countries, it would still decline as a share of GDP in Canada.



Data source: OECD (2013)

Figure 2.2

BERD as a Percentage of GDP

The figure shows BERD as a share of GDP for Canada, the United States, and the OECD average. BERD as a share of GDP has declined in Canada since 2001, widening the gap between Canada and other countries.

To better understand the factors at play in accounting for Canada's persistently low IR&D intensity, the Panel considered two long-standing potential explanations: the degree of foreign ownership of firms operating in Canada and the structure of the Canadian economy.

2.4.1 Degree of Foreign Ownership

The degree of foreign ownership is an argument that has been put forward to account for Canada's low and declining IR&D intensity. Since many multinational firms tend to have their IR&D facilities located close to their headquarters, the high proportion of foreign ownership in Canada could be lowering IR&D intensity. For example, current IR&D expenditures as a proportion of sales are four times higher in Canadian-owned automobile manufacturing firms than in foreign-owned operations in Canada (Statistics Canada, 2012b). Baldwin and Gellatly (2007) observed that such data have led to the argument that the presence of multinationals in Canada has "fostered a branch-plant mentality. The operations

of foreign-controlled firms have been described as ‘truncated’ in that these firms were alleged not to be engaging in value-creating activities such as R&D.” The authors argue, however, that the evidence does not support this concern.

Statistics Canada (2012b) reported that foreign-controlled firms accounted for 35 per cent of IR&D expenditures in Canada in 2010.¹¹ It also reported that expenditure on IR&D as a proportion of sales is higher in Canada among foreign-owned firms in the pharmaceutical and instruments manufacturing industries, and the wholesale trade, information and cultural, finance, and computer services industries.¹² Furthermore, Baldwin and Gu (2005) concluded that, in comparison to Canadian-owned firms, foreign-controlled firms innovate more frequently and are more likely to conduct IR&D. Similarly, Baldwin and Hanel (2000) found that “foreign-controlled firms are often more active in R&D than their domestic competitors [and] they are also more often involved in R&D collaboration projects both abroad and in Canada.”

After the rise in takeovers of Swedish companies, Bandick *et al.* (2011) examined the impact on IR&D in Sweden once a firm had been taken over (given that Sweden has particularly good data on multinationals). They found no evidence that IR&D activity in the firms declined, and their preferred econometric specification suggested that IR&D intensity might actually increase. Zanfei (2000) proposed that the traditional view of multinationals concentrating IR&D at home is being transformed into more complex methods of business organization across national borders.¹³ In Canada, McPetridge (2005) critically reviewed the literature on the impact of foreign ownership on Canada’s IR&D intensity. He concluded that “foreign ownership is a side issue” and deeper structural issues are at play in accounting for Canada’s low IR&D intensity.

2.4.2 Canada’s Changing Economic Structure

A long-standing argument to account for Canada’s low IR&D intensity is the overall structure of its economy. Countries with a greater concentration of industries with high IR&D intensities (e.g., pharmaceuticals, ICT, biotechnology) are expected to have higher levels of IR&D as a share of their GDP. It is a

11 In 2010, the majority of R&D expenditures were by foreign firms in Canada in the mining, paper, pharmaceutical, other chemicals, rubber, primary metal, computer equipment, instruments, and wholesale trade industries (Statistics Canada, 2012b).

12 Statistics Canada (2012b) reports that R&D as a proportion of sales in the information and cultural services industry is more than three times higher among foreign-controlled firms than in Canadian-controlled firms, for example.

13 Hall (2011) reviews the opposite case of whether IR&D investment has shifted away from Canada. She suggests that the attractiveness of investing in rapidly growing emerging economies with cheaper researchers may be one reason for the stagnation in inward IR&D into Canada.

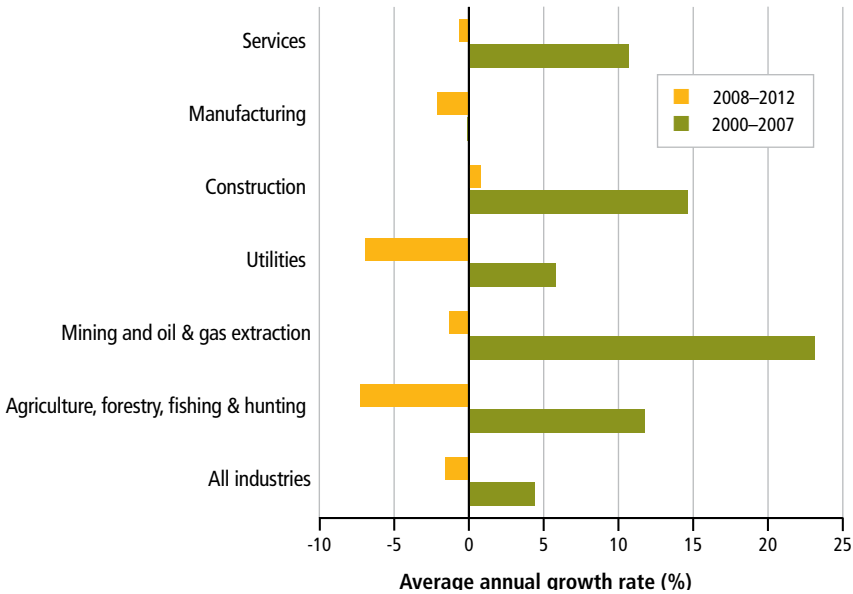
widely held belief that Canada's large resource extraction sector relative to most OECD economies and the low IR&D intensities typical of this sector are largely responsible for Canada's relatively low IR&D intensity. Several studies, however, have concluded that this is not the case (e.g., ab Iorwerth, 2005b; STIC, 2011; CCA, 2009), and OECD (2011a) has suggested that the impact is modest. This section argues that Canada's investment in IR&D remains low by international standards even when the overall structure of the Canadian economy is taken into account. The relatively large share of the Canadian economy accounted for by natural resource industries has almost no impact on the IR&D intensity gap between Canada and the United States. Rather, the relatively low IR&D intensity in the Canadian manufacturing sector is more important.

Although the recession did impact IR&D over recent years (see Figure 2.3), understanding trends in Canada's overall rate of investment in IR&D requires examining the IR&D intensities of Canada's industries (Section 2.3) as well as changes in relative size of industries over longer periods. Canada's overall IR&D intensity may have declined over time because either intensity fell in the most IR&D-intensive sector, manufacturing, or this sector declined as a share of the total economy.¹⁴ The Panel used decomposition techniques to examine the relative impact on the overall IR&D intensity of changing IR&D intensities within sectors, and changes in the relative size of those sectors. These techniques break apart changes in IR&D intensity into constituent parts (Diewert, 1998).

Over the period 2000 to 2008, IR&D intensity increased for services and mining and oil and gas extraction, partially offset by a small decline in manufacturing. This resulted in a positive "intensity effect" of 0.2 percentage points (see Table 2.3). In other words, had the structure of the economy remained the same in this period, the business sector's IR&D intensity would have increased from 1.6 per cent to around 1.8 per cent; instead it declined to 1.4 per cent. The manufacturing sector's share of the total business sector fell from just under 25 per cent to around 15 per cent over the period (Panel analysis based on Statistics Canada, 2012b).¹⁵ This significant reduction in the relative size of the manufacturing sector more

14 The potential importance of the declining relative size of the manufacturing sector in accounting for the changing IR&D intensity of the Canadian economy comes from comparing the rate of decline of the manufacturing sector's relative size in comparison to that of other countries. The lack of recent data for Canada at the OECD hampers such analysis, but the manufacturing sector declined by one-quarter from 19.7 per cent of Canada's GDP in 2000 to 14.6 per cent in 2006. Over this period, the decline in relative size was the third largest decline among 32 OECD economies behind Ireland and Luxembourg (based on Panel analysis of OECD, 2012b).

15 Nominal data are available only until 2008. The business sector accounts for roughly three-quarters of the total economy as measured by GDP. As a share of GDP, manufacturing fell from 19 per cent to 12 per cent from 2000 to 2008 (Statistics Canada, 2013d).



Data source: Panel calculations based on Statistics Canada (2012b)

Figure 2.3

Change in BERD in Canada by Sector, Pre- and Post-recession

The figure shows that the average annual growth rate in BERD was positive until the recession started. The subsequent decline in BERD meant that sector-level expenditures in 2012 had not yet regained their pre-recession levels.

than outweighed the increased IR&D intensity in the other sectors. Without any change in IR&D intensities, the changing structure of the economy on its own would have lowered the business sector's IR&D intensity to around 1.2 per cent (the IR&D intensity of 1.6 per cent in 2000 less the structural effect of 0.4 percentage points). Therefore, the smaller relative size of the manufacturing sector has accounted for the decline in Canada's IR&D intensity since 2000. The sector's share of the economy has fallen more in Canada than in other OECD economies.

Table 2.3
Decomposition of Changes in Economy

	Share of the business sector		R&D intensity		Intensity effect	Structural effect
	2000	2008	2000	2008		
	(%)		(%)		Percentage points	
Agriculture, forestry, fishing & hunting	2.88	2.41	0.42	0.48	0.00	0.00
Mining and oil & gas extraction	7.91	13.37	0.30	0.63	0.04	0.03
Utilities	3.41	2.98	0.64	0.63	0.00	0.00
Construction	6.45	9.30	0.10	0.11	0.00	0.00
Manufacturing	24.36	15.01	4.52	4.45	-0.01	-0.42
Services	55.00	56.92	0.81	1.13	0.18	0.02
Business sector	100.00	100.00	1.61	1.44	0.21	-0.38
Sum				-0.17		-0.17

Data source: Panel calculations based on data from Statistics Canada (2012b, 2013d)

Differences in sectoral trends in IR&D intensities and shares of the economy can be used to account for changes in Canada's overall IR&D intensity. The major factor accounting for the decline in IR&D intensity in Canada since 2000 is the smaller size of the manufacturing sector where most IR&D is located. This change was partially offset by rising IR&D intensity in the service sector.

To further examine the impacts of changes in the Canadian economy since the late 1990s, and the declining relative size of the manufacturing sector in particular, the Panel compared trends in Canada with the United States. Updating a previous decomposition analysis for 1999 undertaken by ab Iorwerth (2005b), the Panel compared the IR&D intensities of Canada and the United States to determine to what extent the structure of the economy played a role in accounting for the much higher IR&D intensity in the United States. OECD data were used to ensure comparability of data across countries. Unfortunately, because of data lags in producing Canadian data for the OECD, the latest data for which this analysis can be undertaken are for 2006. The results, however, can still be usefully compared to the original analysis for 1999.

The Panel's analysis revealed that Canada's low overall IR&D intensity in 2006 can be accounted for by the low IR&D intensity of the manufacturing sector. Basic data for the structure and IR&D intensities of the Canadian and U.S. economies in 1999 and 2006 are shown in Table 2.4. IR&D intensity in the business sector was almost twice as high in the United States as in Canada in 1999, narrowing only marginally by 2006. IR&D intensity in the U.S. manufacturing sector was

much higher than in Canada's manufacturing sector. The share of the less IR&D-intensive service sector was higher in the United States, which, if all else were equal, would act to lower the U.S. economy's IR&D intensity. IR&D intensity declined in the service sector in the United States, but increased marginally in Canada.¹⁶

Table 2.4

IR&D Intensities and Industrial Structure, Canada and United States

	1999				2006			
	IR&D intensity (%)		Share of value added (%)		IR&D intensity (%)		Share of value added (%)	
	Canada	United States	Canada	United States	Canada	United States	Canada	United States
Business sector	1.1	2.0			1.22	1.85		
Agriculture, forestry, fishing & hunting	0.3	0.0	2.5	1.0	0.5	-	1.6	0.9
Mining & quarrying	0.4	0.0	3.8	0.9	0.6	-	8.6	1.7
Manufacturing	3.9	7.9	19.8	16.0	4.5	9.7	14.6	13.3
Electricity, gas & water supply	0.8	0.2	2.9	1.8	0.9	0.1	2.5	1.8
Construction	0.1	0.1	5.1	4.6	0.1	0.2	6.5	4.9
Services	0.5	0.9	66.0	75.7	0.7	0.7	66.2	77.4

Data for IR&D intensity of agriculture, forestry, fishing and hunting and mining and quarrying for the United States is suppressed for data confidentiality. In the subsequent analysis, these values are set to 0%.

Data source: OECD (2012b)

The table provides the basic data on the share of the economy and IR&D intensity of sectors in Canada and the United States.

The most important factors in explaining the 0.82 percentage point shortfall in Canadian IR&D intensity compared to that of the United States in 1999 were the low IR&D intensities of both the manufacturing and service sectors (see Table 2.5). This impact was mitigated by the larger size of the manufacturing sector in Canada, which led to a positive structural effect. Thus the main reason for Canada's low IR&D intensity in 1999 compared to the United States was

¹⁶ This narrowing may be an artefact of revised data methodologies in the United States in 2004, which involved reallocating R&D from services to manufacturing. The mining and oil and gas extraction and agriculture sectors account for a larger share of the economy in Canada, but unfortunately there are no data for R&D expenditures for these sectors in the United States because of data confidentiality.

low IR&D intensity in the manufacturing sector, partly offset by the larger size of the manufacturing sector. The larger relative sizes of the mining and oil and gas extraction and agriculture sectors had no impact.

By 2006, the Canadian manufacturing sector had declined in relative size to almost that of the U.S. sector, decreasing the impact of the structural effect. Comparable levels of IR&D intensity in services as well meant that the negative intensity effect from services was eliminated (possibly because of the data gathering differences discussed in Appendix B). Since the IR&D intensities of the mining and oil and gas extraction and agriculture sectors were so low, their larger relative size in Canada by 2006 again had almost no impact on aggregate differences in IR&D intensity. The explanation for Canada's low IR&D intensity, therefore, is not related to Canada's traditionally large resource extraction sector, but is to be found within Canada's manufacturing sector.

Table 2.5

Decomposition of U.S.-Canada Differences in IR&D Intensity

	1999			2006		
	Intensity effect	Structural effect	Sum	Intensity effect	Structural effect	Sum
	Percentage points			Percentage points		
Agriculture, forestry, fishing & hunting	0.01	0.00		0.01	0.00	
Mining & quarrying	0.01	0.01		0.03	0.02	
Manufacturing	-0.72	0.22		-0.73	0.09	
Electricity, gas & water supply	0.01	0.01		0.02	0.00	
Construction	0.00	0.00		-0.01	0.00	
Services	-0.30	-0.07		0.00	-0.08	
Sum	-0.99	0.17	-0.82	-0.67	0.04	-0.63

Data source: Panel analysis based on OECD (2012b)

The table shows a decomposition analysis of the factors that accounted for differences in the total economy's IR&D intensity between Canada and the United States in 1999 and 2006. The predominant factor in both years is the lower IR&D intensity in the manufacturing sector. In 1999 this effect was partially offset by the larger relative size of the manufacturing sector. This effect was smaller by 2006 because the manufacturing sector was a smaller part of the economy.

Trends in the Manufacturing Sector

To better understand the decline in IR&D intensity in the manufacturing sector, the Panel examined more fine-grained data for the 2000-2008 period on the industries that make up the sector. Two trends emerged: IR&D intensity is rising in less IR&D-intensive industries, and highly IR&D-intensive industries account for a smaller and declining share of the Canadian economy compared to their counterparts in the United States.¹⁷

Rising IR&D Intensity of Less IR&D-intensive Industries

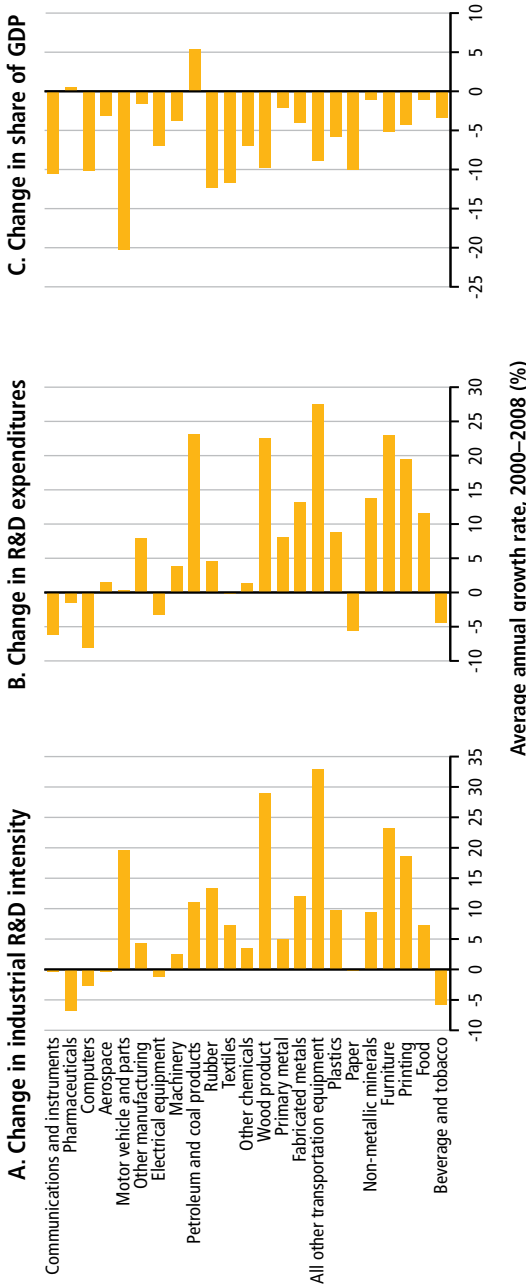
The Panel first looked at the IR&D intensity of Canadian manufacturing industries from 2000 to 2008 as illustrated in Figure 2.4. Panel A shows the change in IR&D intensity, panel B shows the change in the nominal level of BERD, and Panel C shows the change in economic importance of an industry (as measured by share of GDP) over the period. The textiles, wood products, and printing and publishing industries do not spend significant amounts by national standards on IR&D (typically less than three per cent of value added). Since they are maintaining or increasing their expenditures on IR&D despite a contraction in relative size, their IR&D intensities are increasing as a result.

A similar story holds true for the motor vehicle industry in Canada, despite it being much less IR&D intensive than in many other economies. The industry has declined significantly in relative size in Canada over the last decade, but has become much more IR&D intensive as IR&D has been maintained in the country. Finally, higher commodity prices have likely encouraged IR&D expenditures in the refined petroleum industry.

Evolution of Highly IR&D-intensive Industries

The manufacturing sector's IR&D intensity is heavily influenced by the behaviour of IR&D-intensive industries such as pharmaceuticals and computer equipment. The OECD classifies manufacturing industries as low-, medium-, or high-technology based on IR&D intensities and the propensity to buy equipment

17 Data from Statistics Canada (2012b) show that more R&D is performed in manufacturing than in services. Potentially, an alternative classification of firms (Appendix B) in wholesale trade and in scientific research and development services could assign more R&D to the manufacturing sector. Given the significance of R&D in the manufacturing sector, which may be greater than that reported based on the present convention for assignment of firm R&D, the Panel took a closer look at expenditures within this sector.



Industries are ranked according to their IR&D intensities. IR&D intensity is calculated as BERD as a share of value added. Ferrous and non-ferrous primary metal industries are aggregated to the primary metal industry. The communications equipment manufacturing, semiconductor and other electronic component manufacturing, navigational, measuring, medical and control instrument manufacturing, and other computer and electronic products industries are aggregated to the communications and instruments industries because of data availability. Data source: Panel analysis based on Statistics Canada (2012b, 2013d)

Figure 2.4
Evolution of the Manufacturing Sector in Canada

The figure shows how the share of the economy of manufacturing industries and their IR&D expenditures have changed over the years since 2000. IR&D expenditures declined in several IR&D-intensive industries, but the contraction in their economic size meant their IR&D intensities were relatively stable. IR&D expenditures rose in several industries that are not traditionally IR&D intensive, and their IR&D intensities also rose.

embodying IR&D.¹⁸ Based on the data for Canada (Table 2.6), the IR&D intensity of both low- and high-technology industries is roughly equivalent to that of other countries, and slightly above the G7 average. Industries with especially low levels of IR&D in Canada relative to other countries are those classified by the OECD as medium-technology industries.

Using the OECD's classification of industries by technology, Table 2.6 shows that the share of high-technology manufacturing industries (e.g., semiconductor and computer equipment manufacturing) in the Canadian economy was only half its relative size in the United States in 2006. In contrast, the U.S. industry maintained its relative size from 2000–2006. These data suggest that the small and declining share of the Canadian economy accounted for by high-technology manufacturing industries is responsible for the manufacturing sector's low IR&D intensity.

Table 2.6

Manufacturing Industries' Share of the Economy and IR&D intensities, Canada and United States

		High- technology industries	High- and medium-high technology industries	Low- technology industries
Canada	Value added share (%)			
	2006	1.35	4.64	6.21
	1999	2.03	7.89	7.94
	Average growth	-5.72	-7.30	-3.43
	IR&D intensity (%)			
	2006	29.82	10.94	2.02
	1999	27.15	8.30	0.63
	Average growth	1.35	4.02	18.11

continued on next page

18 Hatzichronoglou (1997) laid out the methodology as follows: high-technology industries include aircraft, pharmaceuticals, computers, and communications equipment; medium-high technology industries include electrical equipment, motor vehicles, transport equipment, and chemicals; medium-low technology industries include ship building, coal and refined petroleum products, rubber, and mineral products; and low-technology industries include wood, pulp, paper, food products, and textiles. Baldwin and Gellatly (1998) have proposed alternative procedures to classify industries.

		High- technology industries	High- and medium-high technology industries	Low- technology industries
United States	Value added share (%)			
	2006	2.56	5.67	4.41
	1999	2.68	6.76	5.96
	Average growth	-0.67	-2.50	-4.22
	IR&D intensity (%)			
	2006	33.93	20.64	1.56
	1999	27.66	17.00	0.63
	Average growth	2.96	2.81	13.81

OECD data are used to ensure comparable sector definitions. Data to 2006 are used because of the absence of Canadian data at the OECD. Data for IR&D intensity of medium-technology manufactures in Canada were not available. Average annual growth rates were calculated by the Panel.

Data source: OECD (2012b) and Panel calculations

The table shows basic statistics on manufacturing industries grouped by use of technology. Although IR&D intensity increased in all sectors in both Canada and the United States, there were differences in how the relative sizes of sectors changed. Low-technology industries contracted more as a share of GDP in the United States. Canada had a greater contraction in the share of high-technology industries in the economy than in the United States. The initial share of high-technology industries was smaller in Canada.

Individual high-technology manufacturing industries are much smaller in relative size in Canada than their U.S. counterparts (apart from the “other transport equipment” industry). For example, the relative size of the U.S. computer industry is four times that of Canada. The relative sizes of high-technology industries have also been shrinking faster in Canada than in the United States with the exception of the pharmaceutical industry.¹⁹

Table 2.7 shows that the IR&D intensity of these industries is generally lower in Canada than in the United States. The data assume, however, that IR&D is assigned to the appropriate industry. One of the reasons the average annual growth in IR&D in the pharmaceutical industry is so high in the United States might be the reclassification of IR&D to this industry in 2004, which caused its

19 According to Statistics Canada data, the computer and electronic products industry fell from 1.4 per cent of the economy in 2000 to 0.6 per cent in 2008 after the bursting of the dot.com bubble. R&D expenditures in one of its component industries, communications equipment manufacturing, fell by 53 per cent from 2001 to 2004. Despite the smaller size of the industry, its R&D intensity was roughly the same in 2008 as it was in 2000. Consequently, it is likely that the data reflect the closure of firms rather than a reduction in a firm’s propensity to invest in R&D.

IR&D intensity to increase from 22 per cent to 43 per cent from 2003 to 2004 in the OECD data. It may therefore be inappropriate to compare the IR&D intensities of these industries in Canada and the United States.

Table 2.7
IR&D-intensive Manufacturing Industries' Share of the Economy,
Canada and United States

		Pharmaceuticals	Office, accounting & computing machinery	Radio, television & communications equipment	Other transport equipment
Canada	Value added share (%)				
	2006	0.38	0.06	0.47	0.59
	2000	0.26	0.11	1.05	0.86
	Average growth	6.29	-11.23	-12.65	-6.09
	BERD intensity (%)				
	2006	26.13	48.38	40.28	12.36
	2000	26.89	40.69	37.53	10.57
Average growth	-0.47	2.93	1.18	2.64	
United States	Value added share (%)				
	2008	0.55	0.23	0.66	0.67
	2000	0.54	0.27	1.08	0.66
	Average growth	0.38	-2.11	-5.86	0.09
	BERD intensity (%)				
	2008	56.84	28.39	36.93	30.33
	2000	23.99	19.33	27.77	16.78
Average growth	11.39	4.93	3.63	7.68	

Canadian data only available to 2006.

Data source: OECD (2012b) and Panel calculations

The table compares the performance of high-technology industries in Canada and the United States. The office, accounting and computing machinery and radio, television and communications equipment industries contracted faster in Canada than in the United States. Because of changes in how the United States assigned IR&D expenditures to industry, IR&D intensities may not be comparable. Other transport equipment includes industries such as aircraft and rail equipment manufacturing.

Trends in the Service Sector

Innovation in the service sector tended to come from face-to-face interaction between service providers and their customers rather than from IR&D. This meant that service industries could be highly innovative without spending significant amounts

on IR&D (see Salazar & Holbrook, 2004; Uppenberg & Strauss, 2010). Now, the service sector is becoming an increasingly important performer of IR&D, as shown in Table 2.2. Service sector IR&D is primarily performed in four industries: wholesale trade, information and cultural industries, computer systems design and related services, and scientific research and development services (SRDS), accounting for nearly 80 per cent of all IR&D in the service sector in Canada in 2011. These include highly IR&D-intensive industries such as telecommunications, data processing, video game design, and engineering services. Many research and cutting-edge technology development activities fall under SRDS, including IR&D in the natural and social sciences (e.g., biotechnologies, genetics, and cognitive development). SRDS also represents the activities of many pre-commercial firms in the initial stages of product development, which may eventually be classified within different industries depending on the type of good or service ultimately produced (Lonmo, 2007).

The distinction between manufactured goods and services associated with their provision is also breaking down. Structural changes in the economy mean manufacturing firms now provide services linked to their products, and/or concentrate on IR&D and marketing while outsourcing production to low-cost economies. As a result, the activities of manufacturing firms look more like services.

The evolution in the economy to “factoryless goods production” with value chains spread across several industries and countries is posing challenges for statisticians in assigning IR&D expenditures to particular industries (Doherty, 2012). In 2011 the service sector in Canada spent over \$6.7 billion on IR&D, or 43 per cent of total BERD. This comparatively high level of IR&D performed in the service sector is a distinctive aspect of Canada’s IR&D. Firms in the service sector in the average OECD country account for around one-third of all BERD (OECD, 2011b). As the structure of the economy changes faster than accounting methodologies, these data may be an artefact of assigning IR&D to performing industries rather than to the product of industries for which the IR&D is intended (as discussed in Appendix B). It is therefore likely that Canada’s IR&D in the service sector is in fact more in line with other economies and the manufacturing sector’s IR&D intensity is actually higher. The IR&D in some service industries is performed for other industries, suggesting the IR&D activity should be reclassified to provide a more realistic picture of the distribution of IR&D (as discussed in Chapter 4 of the *Frascati Manual* (OECD, 2002)).

R&D is becoming more important in the service sector as businesses provide more technologically intensive services. Rapidly evolving global supply chains, however, are making it challenging for statistical agencies worldwide to appropriately record

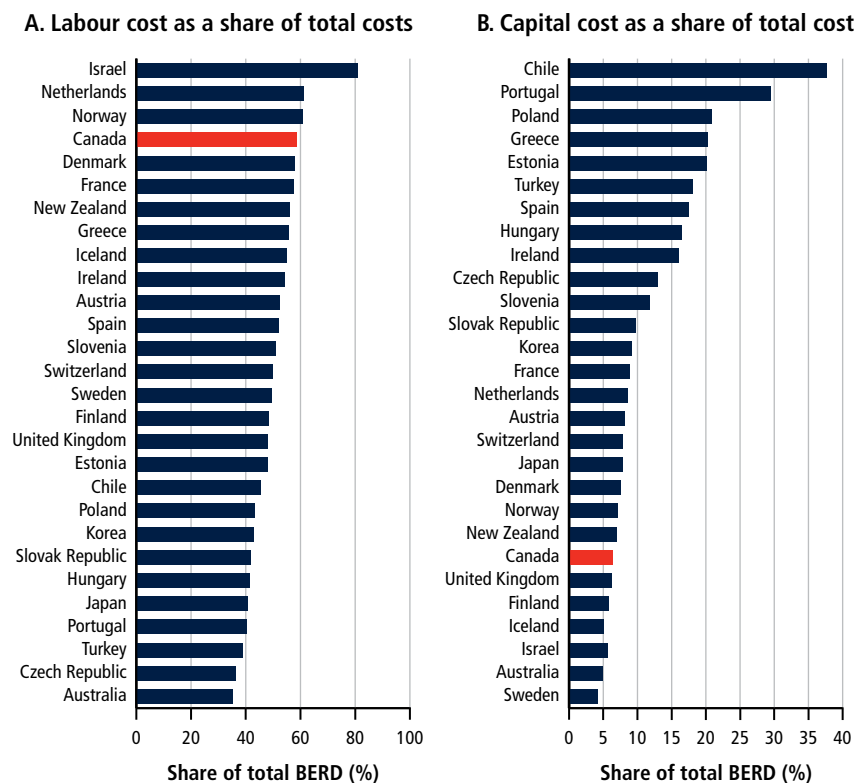
and assign IR&D data. Although the available data do not provide as detailed a view on service sector IR&D as the Panel would have wished, the Panel is convinced that IR&D in the service sector makes important contributions to the Canadian economy.

2.5 INTERNATIONAL COMPARISONS OF IR&D PERSONNEL AND CAPITAL

The levels of IR&D personnel are highly correlated with IR&D expenditures as around one-half of IR&D spending is typically dedicated to employee compensation (Jaumotte & Pain, 2005). However, IR&D in Canada appears to be particularly labour intensive. On average between 2006 and 2010, OECD data show that the Canadian business sector spent just over \$9 billion on wages and salaries in IR&D out of total BERD of around \$16 billion, or around 57 per cent (see Figure 2.5, panel A). In contrast, investment in R&D capital averaged to around \$1 billion for the same period. This is just over six per cent of total BERD, and relatively low by international standards (see Figure 2.5, panel B). The balance of BERD was taken up by other purchases such as raw materials and supplies. Overall, this implies that IR&D in Canada is relatively more personnel intensive and relatively less capital intensive when compared to other countries.

The relative cost of a researcher is low in Canada compared to other countries. Table 2.8 lists the total number of IR&D personnel in 2009 and the ratio of BERD to personnel. For the majority of OECD countries, total BERD is in excess of US\$100,000 per researcher. Australia is at the top of the list, while Canada ranks near the bottom. The two countries have roughly similar levels of BERD; however, in Canada, those expenditures are divided among more than double the number of researchers. In principle, total expenditure per number of researchers could be higher either because of a higher wage rate for a researcher or higher capital investment per researcher.

Contrary to what might be expected from the BERD data in Canada compared to other countries, the number of IR&D personnel as a proportion of the population is relatively high in Canada. When IR&D personnel are examined in relation to total population, Canada is in the middle of the pack: not among the world leaders such as Israel, Denmark, Sweden, and Finland, but still above many of its peers (last column, Table 2.8). The implication from all of these measures is that, relative to other countries, Canada's IR&D is personnel intensive, and the capital intensity of IR&D in Canada is lower than in other countries. The low rate of capital spending in IR&D in Canada is in keeping with the low rates of investment in machinery and equipment in the overall economy (Baldwin *et al.*, 2008).



Data are calculated as averages over a period of up to 5 years. Because of data availability, expenditures for some countries are based on a single year. No data are available for the United States. Total costs also include expenditure on materials and other inputs.
Data source: Panel calculations based on OECD (2013)

Figure 2.5

Labour and Capital Expenditure as a Share of Total R&D Costs, 2006–2010

The figure shows that labour costs account for a relatively high share of total IR&D costs in Canada, and capital costs for a relatively small share.

One potential explanation for Canada’s relatively high level of investment in labour versus capital is a difference in wages for IR&D personnel. An implicit “average wage” for researchers can be obtained by dividing the level of expenditures on labour by the number of researchers employed in IR&D (using OECD data in both cases). This is a rough measure, but it suggests the wage rate for researchers in Canada is relatively low (see Figure 2.6). Low wage rates often imply that not only is IR&D more labour intensive (as it is in Canada), but also that more IR&D is done (which is not the case in Canada).

Table 2.8
BERD and R&D Personnel, 2007–2011

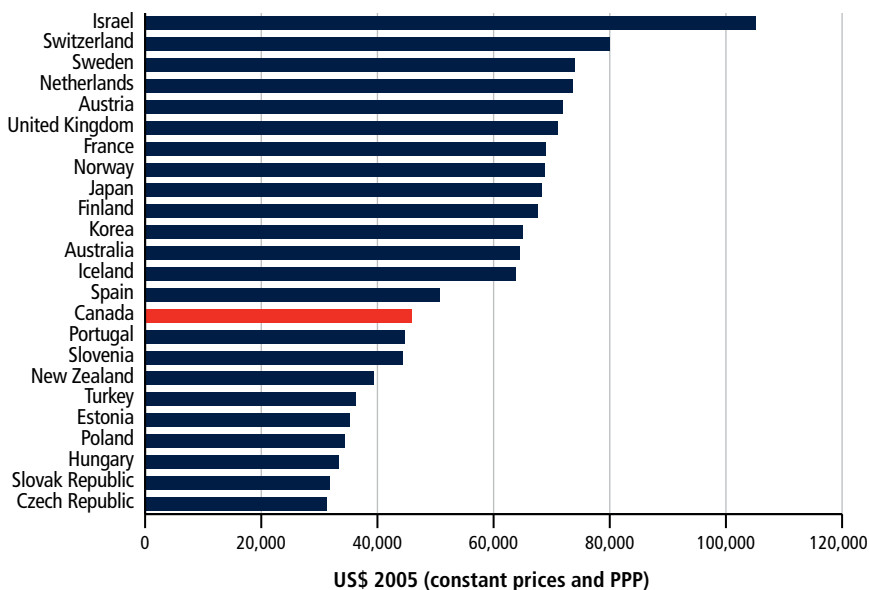
	Total IR&D personnel (full-time equivalent)	BERD per IR&D personnel (\$ thousands)	IR&D personnel per thousand population
Australia	54,800	189.21	0.25
Japan	619,251	166.45	0.48
Switzerland	39,832	160.27	0.52
Korea	208,901	156.76	0.43
United Kingdom	153,664	149.21	0.25
Sweden	53,922	145.69	0.58
Finland	32,429	142.89	0.61
Austria	37,646	140.98	0.45
Israel	52,145	133.91	0.70
Netherlands	49,246	120.13	0.30
Portugal	13,813	119.93	0.13
France	213,361	119.91	0.34
Norway	17,716	117.14	0.37
Iceland	1,449	116.17	0.40
Turkey	25,861	104.93	0.04
Spain	92,150	99.93	0.20
Slovenia	6,096	90.37	0.30
Czech Republic	26,042	86.48	0.25
Hungary	12,476	82.80	0.12
Poland	13,845	82.47	0.04
Slovak Republic	2,689	77.03	0.05
Canada	157,593	76.95	0.47
Estonia	1,819	75.74	0.14
New Zealand	8,200	70.04	0.19

Dollar figures are in constant 2005 U.S. dollars, adjusted for purchasing power parity (no data for the United States). Countries are ranked according to BERD per R&D personnel.

Data source: OECD (2013) and Panel calculations

The table shows the total number of personnel engaged in IR&D, BERD divided by the number of personnel, and the number of IR&D personnel as a share of the total population. BERD per researcher employed is relatively low in Canada, but the number of researchers as a share of the population is relatively high. These data are consistent with the relative labour intensiveness of Canada's IR&D.

There are several potential explanations for why the number of researchers is relatively high in Canada compared to other countries but the implied labour cost is relatively low. First, Canada has a highly educated population, and the relatively abundant



Notes: Data represent total labour costs (2005 U.S. dollars with constant prices and adjusted for purchasing power parity (PPP)) divided by the number of researchers. Data are averaged over 2006-2010, but, because of data availability, expenditures for some countries are based on a single year. No data are available for the United States.
Data source: Panel analysis based on OECD (2013)

Figure 2.6

Implicit Average Researcher Wage

Even after adjusting for the cost of living, the implicit wage rate for a researcher undertaking IR&D in Canada is relatively low compared to leading OECD economies.

supply of potential IR&D personnel may mean that researchers cost less. About 50 per cent of the working-age population in Canada holds a tertiary qualification, compared to just 30 per cent on average in OECD countries (OECD, 2011a).²⁰ Likewise, Canada's youth do well in many international educational assessments. In the latest round of the OECD's Program on International Student Assessment (PISA), Canada ranked sixth overall. Despite a highly educated population in general, Canada produces relatively few PhDs (STIC, 2011; CCA, 2009; OECD, 2012a). The number of doctoral graduates in Canada as a percentage of the population is significantly below the OECD average (OECD, 2011a). Canada's

²⁰ OECD (2011a) also notes that this high proportion of tertiary attainment is largely the result of the popularity of shorter, vocationally oriented programs: some 26 per cent of 25–34 year-olds in Canada completed such programs, compared to the OECD average of just 11 per cent. Community college diplomas and degrees are a much more common credential in Canada than in other countries such as the United States (CCA, 2009; OECD, 2011b).

relatively high unemployment rate for doctorate holders among OECD countries (OECD, 2012a) is at odds with the seemingly high use of R&D personnel. Canada may be compensating for its relatively low number of PhD graduates with a higher proportion of people with other qualifications. This conjecture cannot be verified, however, because internationally comparable data are not currently available.²¹

Second, the structure of the Canadian economy affects relative labour costs. The Panel compared labour costs per researcher across Canadian industries, using data from Statistics Canada (2012b). For 2007, the last year for which numbers were available for all industries, the implied “wage rate” was around \$100,000 for a researcher in the oil and gas extraction and electric power industries, and around \$80,000 in the finance, communications equipment, primary metal, semiconductor, petroleum and coal products, and aerospace industries. At the other end of the scale, wage costs in agriculture, construction, furniture manufacturing, and printing were \$35,000 or less. If fewer IR&D activities take place in those high-paying industries in Canada than in other countries, the implied wage cost of a researcher will be less. By the same token, if Australia is a centre for IR&D in oil and gas extraction, it will have a higher average wage for researchers.

Third, more R&D workers are employed in small firms in Canada, as discussed in Section 2.6. Although the reasons are complex, workers are generally paid more in larger firms (Oi & Idson, 1999). If proportionately more R&D workers are employed in start-ups in Canada, their compensation may be through stock options rather than wages. Therefore, full labour costs may not be reflected in the data. Fourth, there may be low demand for IR&D workers in Canada.

2.6 DISTRIBUTION OF BERD BY FIRM SIZE IN CANADA

IR&D expenditures in most countries tend to be highly concentrated in larger firms, with a significant share of national IR&D often undertaken by a select few industry leaders. Canada is no exception, with the majority of IR&D spending occurring in firms with over 500 employees. Increasingly, however, IR&D is being undertaken in a broader range of firms in Canada, less in larger firms, and proportionately much less than in larger firms in the United States.

21 Around 40 per cent of R&D personnel in Canadian businesses are classified as technicians, technologists, or other support staff, rather than as R&D professionals (Statistics Canada, 2012b). This proportion, however, is not far from the norm for OECD countries (OECD, 2012b). Statistics Canada (2012b) reported that 5 per cent of Canada’s professional R&D personnel in 2010 had no qualification, 8 per cent had a college degree, 60 per cent had a bachelor’s degree, 18 per cent had a master’s, and 8 per cent had a PhD. Comparable data from the OECD are not yet available.

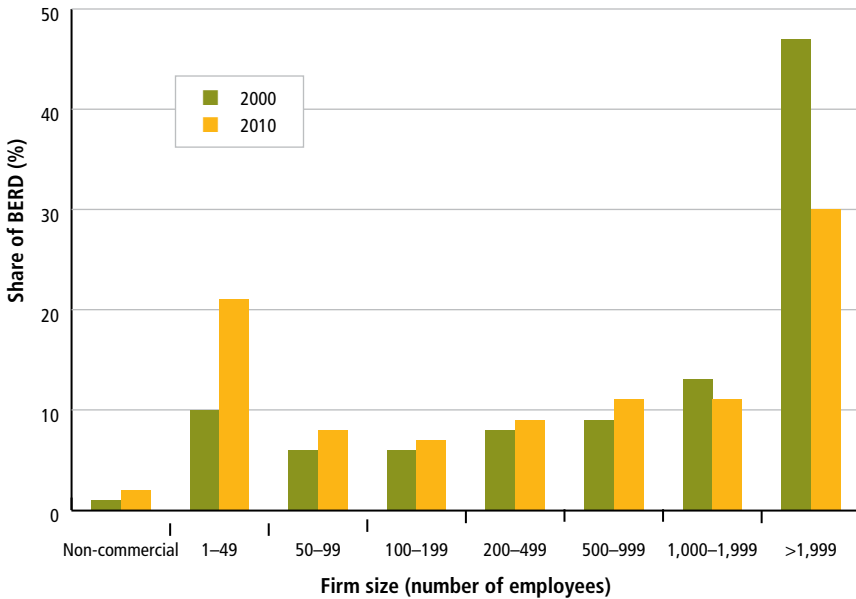
Successful innovations from IR&D have come from both small and large firms. Small firms can be more entrepreneurial and dynamic, testing the market with their new products. Market-leading innovations have also come from large research laboratories owned by global multinationals. Although the question of whether smaller or larger firms are more important for innovation has long been a topic of research, no clear theoretical answer has emerged. Schumpeter (1942) hypothesized that larger firms were more important because they had the resources to spend on IR&D, had access to finance, and reaped economies of scale. Since large firms are better able to keep the benefits themselves, rather than the benefits spilling over to other firms, they have more incentives to innovate. Arrow (1962), however, described the “replacement effect,” whereby large firms with steady profits have less incentive to develop new products that might disrupt their existing business. These arguments have been buttressed by beliefs that large firms tend to be bureaucratic and stultify their innovators, while small firms are more entrepreneurial.

Researchers have found it difficult to disentangle these possibilities. There is clear evidence that the level of IR&D expenditures is greater for larger firms. Songsakul *et al.* (2008) found that IR&D intensity declines as firm size increases among firms that perform IR&D in Canada. They also concluded, however, that the propensity to undertake IR&D is 15 times as great in firms with more than 500 employees than in those with fewer than 100 employees. In a review of international evidence and recent theoretical advances, Cohen (2010) suggested that the importance of scale economies for IR&D means larger firms have an advantage in spreading costs across projects and “greater output confers an advantage in realizing returns to R&D.”

Turning to the data for Canada, the number of firms reporting IR&D expenditures has increased significantly over the past 15 years. In the late 1990s, roughly 10,000 firms were performing IR&D in Canada, but, by 2008 (the latest year for which there are data), that number had grown to nearly 25,000 firms, or around 2.5 per cent of all Canadian enterprises with one or more employees (Statistics Canada, 2012b). Statistics Canada (2012b) has suggested that more firms are adopting IR&D as a business strategy.

As the number of IR&D performers has grown, smaller firms represent a larger share of Canadian IR&D spending. In the 1980s, around one-half of all IR&D spending took place in the top 25 firms; by 2011, that share had dropped to roughly one-third (Statistics Canada, 2012b). Figure 2.7 shows that the proportion of IR&D expenditures of firms with 2,000 or more employees was much smaller in 2010 than in 2000, and the proportion of firms with fewer than 50 employees

was greater. In contrast, three-quarters of IR&D in the United States in 2009 was performed by firms with 1,000 or more employees (see Figure 2.8). After taking into account differences in economy size, the data suggest that the lower level of IR&D spending in Canada is spread over a greater number of firms that are, on average, smaller in size.



Data source: Panel calculations based on Statistics Canada (2002, 2012b)

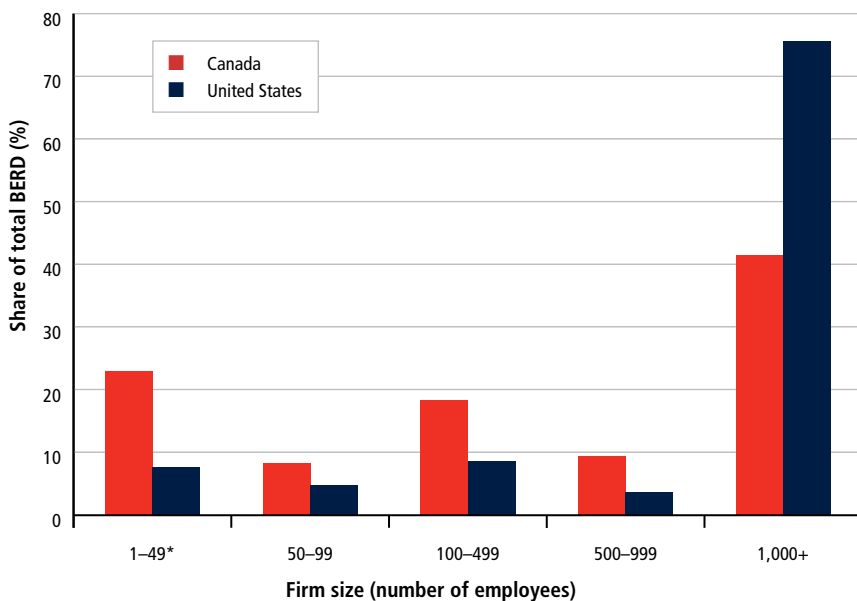
Figure 2.7

BERD by Employment Size of Performing Firm in Canada, 2000 and 2010

The figure shows the share of BERD undertaken by firms of different sizes where size reflects the number of employees in the performing firm. The share of BERD undertaken by smaller firms in 2010 is larger than in 2000. Firms with 2,000 or more employees undertake a smaller share of BERD.

Some of these patterns, which indicate a limited number of large firms performing IR&D in Canada, are also evident in trends in individual firms. Firms are required to report spending on IR&D in their financial accounts, but the definition of IR&D for that purpose may differ from the *Frascati Manual* definition of IR&D.²² Data from consulting firm The Impact Group show that large absolute levels of IR&D expenditures are concentrated in relatively few firms in Canada. The data, which

²² There may be inconsistent reporting of expenditures on IR&D consultants, for example. For a discussion of accounting for IR&D in New Zealand, see Palmer (2009).



*Canadian data are for firms with more than one employee. U.S. data are for firms with five or more employees.
Data source: Panel calculations based on Statistics Canada (2012b) and Rausch (2010)

Figure 2.8

BERD by Firm Employment Size in Canada and United States, 2009

The figure compares the distribution of BERD across different firm sizes in Canada and the United States. A greater share of IR&D expenditures tends to take place in larger firms in the United States.

distinguish between IR&D expenditures of Canadian firms and subsidiaries of foreign corporations in Canada, do not present an entirely accurate picture of IR&D taking place in Canada (see Table 2.9). The IR&D expenditures attributed to Canadian firms include *all* the IR&D undertaken by those firms around the world, and not just that occurring in Canada. For example, Magna undertakes 55 to 60 per cent of its IR&D in North America with other IR&D undertaken in countries such as Austria, Brazil, China, and Hungary.²³ Although some of the Canadian IR&D activities of Nortel Networks were taken over by other companies, its decline meant a significant IR&D performer was removed. Its 2000 annual report stated that half of its R&D workforce was based in Canada, which suggests that it spent roughly \$3 billion on IR&D in Canada. Table 2.9 also highlights the

23 Furthermore, takeovers of foreign companies will result in more R&D expenditures being added to the Canadian parent company's totals. For example, Bombardier has purchased European firms in the rail industry, and the R&D of acquired firms will now be reported as increases for the Canadian parent company. See Dachs *et al.* (2012).

importance of foreign-owned firms in Canada's IR&D performance, with 5 of the top 10 performers in 2011 being foreign owned. This share could be higher if only the Canadian expenditures of Canadian firms were included.

Table 2.9
Firms with Largest Expenditures on IR&D in Canada, 2000 and 2011

2000		2011	
	\$ millions		\$ millions
Nortel Networks	5,948.2	Research in Motion	1,542.0
Pratt & Whitney Canada*	331.0	Bombardier	1,336.3
Magna International	246.5	BCE	569.1
Ericsson Canada*	237.8	Magna International	519.3
ATI Technologies	224.3	IBM Canada*	500.0
PMC Sierra*	203.0	Pratt & Whitney Canada*	473.0
Atomic Energy of Canada	173.4	Atomic Energy of Canada	441.9
JDS Uniphase	168.4	Ericsson Canada*	323.0
Mitel	152.9	AMD*	283.3
Bombardier	132.2	Alcatel-Lucent*	237.0

ATI Technologies was taken over by AMD. Ericsson bought some of Nortel's operations.

* Foreign subsidiary data include expenditures on IR&D in Canada. Data for Canadian firms include global spending.

Data source: ReSearch Infosource (2001, 2012)

The table shows expenditures on IR&D by leading Canadian firms globally and by foreign firms in Canada. Global IR&D expenditures by several Canadian firms have increased, but Nortel Networks' demise resulted in the removal of a large IR&D spender.

European Union BERD data identify the largest IR&D performers in the world (EC, 2013) by the location of the head office of a firm performing IR&D rather than by the country in which IR&D takes place. In contrast to the data from The Impact Group, these data do not provide information on subsidiaries of foreign companies operating in Canada.²⁴ Table 2.10 shows that the Canadian firms spending the most on IR&D were Nortel Networks in 2004 and Research in Motion in 2011. Despite Research in Motion more than doubling its IR&D expenditures over this period, it did not reach Nortel's 2004 expenditure level.

²⁴ It is unclear why the Canadian-based firms included in the European Union list differ from those in ReSearch Infosource (2012).

R&D has increased significantly among global firms. A firm spending around €50 million in IR&D in 2006 would have seen its rank among global IR&D performers fall by around 400 places if it had not increased its IR&D expenditures by 2011. Only 6 of the top 1,000 global IR&D performers in 2011 were Canadian firms.

Table 2.10

BERD and Global Rank of Top 10 Canadian Firms, 2004 and 2011

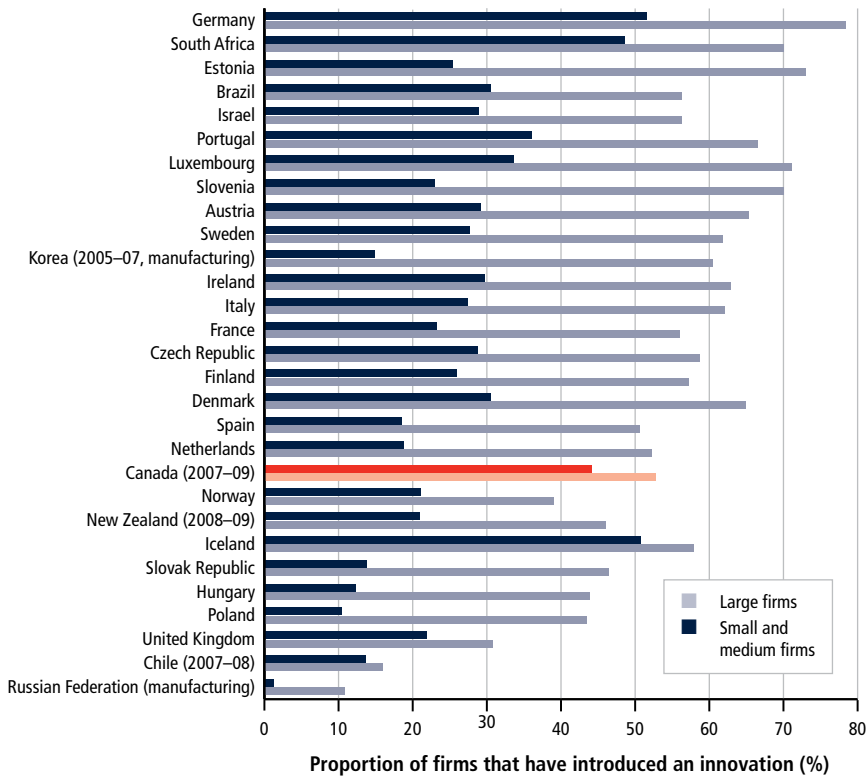
2004			2011		
	Rank	€millions		Rank	€millions
Nortel Networks	53	1,441	Research in Motion	91	1,204.9
ATI Technologies	262	199	Bombardier	116	915.2
Alcan	301	176	Thomson Reuters	201	475.3
Bombardier	475	91	CAE	818	79.9
Cognos	544	78	Constellation Software	828	78.6
Research in Motion	561	74	Sierra Wireless	959	63.5
Ballard Power	623	67	Valeant Pharmaceuticals	1150	50.8
Creo	653	62	Aastra Technologies	1244	45.8
CAE	745	51	Mitel Networks	1254	45.3
Zarlink	776	48	Exfo	1451	37.0

ATI Technologies, Alcan, Cognos, Creo, and Zarlink were taken over, and are therefore no longer classified as Canadian firms by 2011. These operations may continue to have IR&D expenditures in Canada.

Data source: EC (2005, 2012)

The table compares leading Canadian-owned firms' expenditures on IR&D in 2004 and 2011. Several Canadian firms spent more in 2011 and were ranked higher among global firms. However, firms in other countries also increased their IR&D spending, so Canada had fewer Canadian-owned firms in the top 1,000 spenders worldwide.

The overall picture of burgeoning activity in smaller firms in Canada, but a somewhat starker one of larger firms, is supported by innovation surveys, which are discussed at greater length in Chapter 4. On the one hand, smaller companies in Canada are among the most likely to have adopted an innovation (see Figure 2.9, which uses data available for OECD economies) although this finding may be affected by a higher employment threshold for firms in the Canadian survey. On the other hand, larger Canadian firms are less likely to have adopted an innovation than their counterparts in most other countries.



Notes: Data for Canada cover firms with 20 or more employees, which is a higher threshold than for other countries. Dates by the country name indicate the different sampling period.
Data source: OECD (2011a)

Figure 2.9

Propensity to Innovate by Firm Size, 2006–2008

The figure shows the propensity of a firm to introduce a product or process and marketing or organizational innovation. In most countries, larger firms tend to introduce more innovations than smaller firms. In Canada larger firms are less likely to introduce an innovation than in other countries, but smaller firms are more likely. However, differences in the size thresholds for including firms in the survey may limit comparability across countries.

These data can also be examined in light of other analyses in Canada on the variation in productivity by firm size, as summarized by Leung *et al.* (2008). The authors state that the smaller average size is one of the most distinctive structural features of Canadian firms relative to those in the United States. In the late 1990s, the employment share of firms with 500 or more employees was 13.6 percentage points lower in Canada than it was in the United States. The productivity of firms with either fewer than 20 employees or 500 or more employees was one-fifth lower than U.S. counterparts whereas productivity of intermediate-sized firms

was the same. Firms grouped into the small or large employment categories were disproportionately smaller than their U.S. counterparts: a Canadian firm with 500 or more employees was 50 per cent smaller than its U.S. equivalent.

The evidence summarized by Acemoglu and Cao (2010) suggests that small and large firms develop different strategies for innovation and IR&D. Large incumbent firms tend to develop more incremental improvements and process innovation than smaller firms. The finding that small firms are better at “exploration” IR&D and large firms are better at “exploiting” their current products (Akcigit & Kerr, 2010) is consistent with firm distribution data on IR&D in the United States. Consequently, healthy IR&D may involve a mix of both small and large firms.

2.7 CONCLUSION

Data on IR&D expenditures and personnel are useful in characterizing the overall IR&D landscape in Canada. IR&D is proportionately smaller in Canada than in other countries, and relatively personnel intensive and less capital intensive. Even once differences in industrial structure are taken into account, Canadian investment in IR&D remains low. Canada was one of only a very few OECD countries to register negative average annual growth in IR&D intensity since 2000. Low IR&D intensity in Canada cannot be accounted for by the traditionally large size of the resource extraction sector or the degree of foreign ownership of firms operating in the country. Rather, low and declining IR&D intensity in the manufacturing sector, which is roughly half that of the G7 average, is largely responsible.

In international comparisons across industries, Canada’s medium-high technology industries (e.g., auto manufacturing and parts, chemicals excluding pharmaceuticals, other manufacturing) have low IR&D intensities by international standards. In contrast, the IR&D intensity of Canada’s high-technology industries (e.g., pharmaceuticals, aerospace, communications, computers, instruments) as a group is roughly on par with their international peers. These industries, however, account for a smaller share of the manufacturing sector in Canada compared to the United States, and some high-technology manufacturing industries have contracted markedly since 2000. Some low-technology Canadian industries are increasing their IR&D intensities, but their low base level of IR&D means that these industries alone cannot drive Canada’s overall IR&D intensity higher.

The Panel believes that the low IR&D intensity in the manufacturing sector can be partially accounted for by the current assignment of some IR&D expenditures to service industries such as wholesale trade and scientific research and development services rather than to the manufacturing industries that they most likely serve.

The increase in the number of IR&D performers in Canada during a period with low or declining growth in overall IR&D expenditures suggests that IR&D has become less concentrated in the past decade. It is now more widely dispersed over a greater number of firms. Overall, fewer large firms undertake IR&D in Canada than in highly IR&D-intensive countries. This could be holding back Canada's overall IR&D performance because economies of scale in IR&D are not available, and larger firms can help take the successes of smaller firms to a broader market.

Data on IR&D expenditures and personnel, although extremely useful, cannot tell or explain the full story of the state of IR&D in Canada. These indicators are *inputs* into the IR&D process. The next two chapters look at various indicators of IR&D *outputs* and *outcomes*.

3

Industrial R&D Outputs: Patents and Publications

- **Patents**
- **Publications**
- **Conclusion**

3 Industrial R&D Outputs: Patents and Publications

Key Findings

- Canada has the 12th highest rate of patents granted in the world, and the impact of Canadian patents is relatively high. Canada is responsible for 1.1 per cent of patents filed in Europe, Japan, and the United States, and around 4 per cent of the world's scientific journal articles.
- Canada accounts for a relatively large share of world patents in pharmaceuticals and medicines (drugs) and communications technologies. For example, in 2011, Canada had the sixth highest share of drug patents in the world.
- The average quality of publications in Canada is at or above the world average for many industries. Canadian industry patents are cited in other patents about 20 per cent more than the world average, suggesting a relatively high impact on development of related technologies.
- High rates of publishing scientific output in service industries suggest that the service sector produces more new ideas than are suggested by conventional input measures, which show a higher proportion of R&D expenditure in manufacturing. Publications in the service sector may be a means of educating consumers and attracting talented employees.

IR&D yields new products and ideas valuable for commercial markets and the advance of scientific knowledge. Firms frequently choose to protect their intellectual property in the form of a patent when they believe their research could translate into new commercial products. Patents and publications provide an important complementary perspective on industry-based data by capturing some of the outputs of IR&D. As OECD (2007) points out, “patenting by industry provides valuable information on industries’ technological strengths.” Similarly, industrial researchers may seek to share their knowledge through scientific publications.

The Panel began by examining patents by technology field, the conventional method of reporting patent statistics. To deepen its understanding of IR&D in Canada, the Panel then commissioned a study of patents and publications in Canada (undertaken by Science-Metrix; see Appendix A for more details). The study allowed for systematic comparison of patenting and publication activities across industries, as well as analysis of the impact of Canadian IR&D on specific industries as reflected by patent and publication citations.

3.1 PATENTS

With so much vested in developing a new product, a patent can form part of a firm's strategy on intellectual property to capture the returns from its innovations. A patent is a legal instrument protecting an invention. As such, patents can be an important indicator of IR&D activity. An idea that is patented must be valuable or time and money would not have been expended in patenting it. It must also have met the test of novelty or it would not have passed the scrutiny of examiners at the patent office. Patent data, which include rich detail on technology and the geography of where patents are developed and assigned, allow links to be developed to other economic metrics.²⁵

Despite these significant advantages, the limitations of patents as indicators of IR&D have been well known for some time (Griliches, 1990). Not all ideas are patentable because they may be too tacit to describe in words (e.g., new methods of organizing work). Not all inventions are patented because firms may want to keep the idea completely secret rather than describe its workings in a patent application. Counts of the number of patents also do not take into account differences in the value of patents: some patents are far more commercially valuable than others (Pakes, 1986).

Nevertheless, research has long shown the strong relationship between expenditure on IR&D and the number of patents granted (Pakes & Griliches, 1984). Firms tend to apply for a range of patents to protect their core technology. The aim is to prevent competitors from getting patents that cover the best way to apply that technology. Since the inventor is often not aware of all the potential customer applications of a technology, however, knowing in advance which patent will be the most valuable is not always possible. Although significant costs are associated with patent prosecution, patents may be the most important means of protecting intellectual property for smaller, early-stage firms, particularly as the cost of applying for a patent is low.²⁶

25 Hall and Harhoff (2012) have reviewed more recent developments in the economics of patents. The role of publications in the business sector is reviewed by Stephan (1996).

26 Cohen *et al.* (2000) surveyed firms on their strategic decisions on protecting and their innovation, including through patents, secrecy, lead-time advantages, and use of complementary marketing and manufacturing capabilities. The ability to protect intellectual property through these mechanisms will likely differ significantly across industries. Arundel and Kabla (1998) examined European data and found that 36 per cent of product innovations across all industries were patented. At the high end, 79 per cent of pharmaceutical innovations were patented.

The OECD *Patent Statistics Manual* provides guiding principles for using patent indicators, as well as recommendations for compiling and interpreting them in the context of S&T measurement (OECD, 2009b). In general, the Panel followed the OECD guidelines, and used several of the elements of patent data. First, patent applications must include the geographic locations of the individuals who developed the new idea, and of the firm that owns the patent. The generation of knowledge is linked to the addresses of the inventors whereas profits are linked to ownership. Second, since patent data include information on the technology field to which the invention belongs, the technology can be linked to an industry and a geographic area (such as a province).

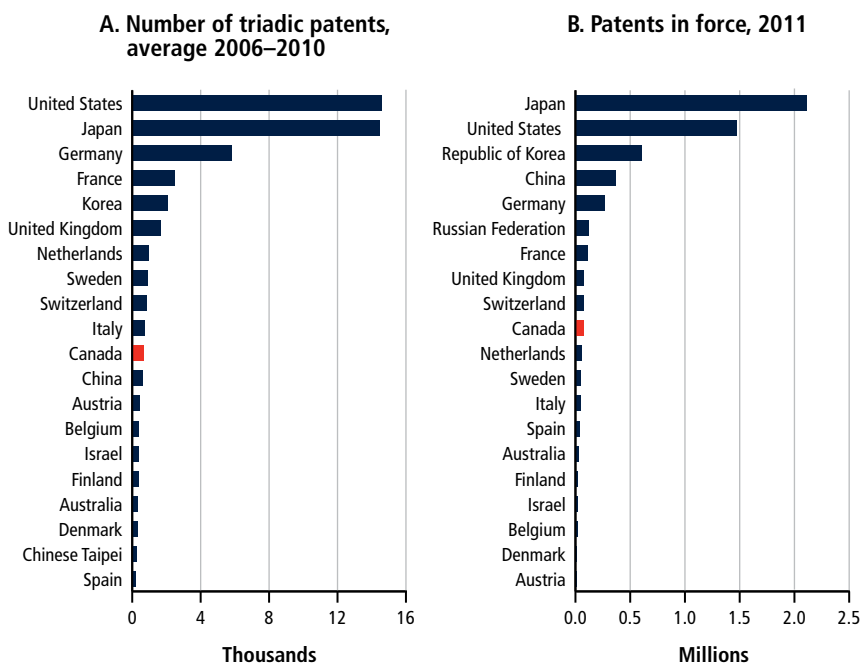
3.1.1 International Comparisons of Overall Patenting Performance

There is a well-known bias for firms to patent most with the patent office in their own country, such as Japanese firms filing at the Japan Patent Office. To control for this home bias in comparing patent counts, the OECD gathers and harmonizes “triadic” patent data to generate patent counts that more closely reflect a world total. Triadic patents comprise patents filed at the world’s three main patent offices: European Patent Office, United States Patent and Trademark Office, and Japan Patent Office. Canada is an exception to the home bias issue in that Canadian firms tend to patent disproportionately at the United States Patent and Trademark Office (USPTO). Looking only at patents filed in the United States would therefore tend to overstate Canada’s share of the world’s inventions.

According to OECD triadic patent data, Canada consistently had the 10th or 11th highest rate of patenting (see Figure 3.1).²⁷ Canada’s share of triadic patents rose from 0.9 per cent in 1985 to reach an estimated 1.1 per cent in 2011. However, the explosion in patenting in China over the last decade means that Canada has had the 12th highest rate of patenting in the world since 2009.

Obtaining data on the total number of patents held in a country (the “stock”) is difficult. Once granted, patents can normally remain valid for up to 20 years from the date of application. To maintain a patent’s validity, however, a fee must be paid annually. If a patent holder determines that the patent does not have commercial value, it can be forfeited by not paying the fee. Calculating the number of total patents held at any one time is therefore not a matter of simply adding up patents issued. The data on the number of patents in force, which are the basis for panel B of Figure 3.1, are not available on an industry or technology basis.

27 Applying for “triadic” patents may be important for large companies, but Japanese patents may be too expensive for small companies because the costs of translation and Japanese legal representation can be prohibitive.



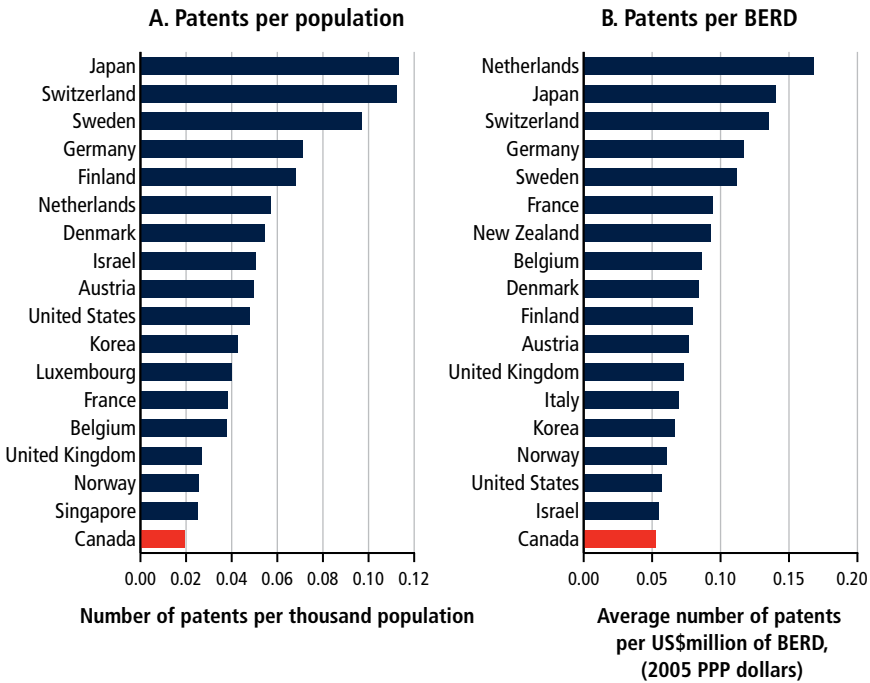
The number of triadic patents is by priority date. Patents in force data are total counts by applicants' origin.
Data source: Number of patents from the OECD (2013); patents in force from WIPO (2012)

Figure 3.1

Flow and Stock of Patents Held

The figure shows that Canada is a major producer of patents by world standards. Canada holds the 10th highest number of patents.

Larger countries tend to produce more patents because they have more researchers. Hence, adjusting the number of patents for population gives a sense of how effective an economy is in producing research outputs. Some countries may be better at translating limited IR&D into patents. Figure 3.2 suggests that many smaller European economies are strong performers on both these metrics. Countries with proportionally greater levels of BERD than Canada are capable of translating that spending into even greater patent counts.



Patents are triadic patents. Data are averaged over 2006–2010.
Data source: Panel calculations based on OECD (2013)

Figure 3.2

Patents per Population and per US\$ Millions of BERD, 2006–2010

The figure shows that many countries produce more patents than Canada in proportion to either their population or BERD.

3.1.2 International Comparisons of Patents by Technology Field

As noted previously, Canadian firms tend to file patents disproportionately at the USPTO. To provide a more detailed look at patent activity in Canada by technology, this section focuses on USPTO data. The USPTO allocates the patents it grants into 403 technology fields. The fields in which technologies advance can change rapidly. For example, database and file management advanced from being the 51st most patented field in 2000 to the 7th in 2011 (see Table 3.1). From a longer-term standpoint, a technology identified as a strength today may not be a strength tomorrow.

Table 3.1

Ten Technology Fields with Most Active Patenting in 2011, and Rank in 2000

	Rank, 2000	Rank, 2011
Multiplex communications	12	1
Drug, bio-affecting and body treating compositions	1	2
Active solid-state devices	7	3
Semiconductor device manufacturing: Process	2	4
Telecommunications	11	5
Multicomputer data transferring	31	6
Database and file management or data structures	51	7
Financial, business practice, management, or cost/price determination	57	8
Chemistry: Molecular biology and microbiology	3	9
Image analysis	25	10

Fields are ranked according to the rate of patenting in 2011. The second column shows the rank of patenting activity of these fields in 2000.

Data source: Panel analysis based on USPTO (2012)

The table shows the variation in the fields with the most active rates of patenting. Although drugs development is a technology field with a consistently high rate of patenting, the rates in other technology fields have increased (such as in business) while others have declined.

Patenting is highly concentrated. Ten technology fields alone accounted for 20 per cent of all patents granted based on USPTO data. The Panel focused on the 50 technology fields in which patenting is most active, which accounted for 60 per cent of all patents issued by the USPTO from 2007 to 2011. Table 3.2 ranks these technology fields by share of all patents issued. For example, all drug patents issued by the USPTO amount to 3.2 per cent of all patents issued (as shown in the fifth column). The table also displays the average number of patents granted to Canadian industry over this period (second column), Canada's share of world patents in a technology field (third column), and the rank of Canada's patent share by field (fourth column). The data show, for example, that drugs accounted for an average of 179 patents annually in Canada from 2007 to 2011, or three per cent of the world's total. The highest share of the world's patents held by Canada was for multiplex communications at 4.2 per cent, followed by telecommunications at 3.9 per cent. Canada's 3 per cent of drugs patents was its seventh highest share.

To help identify areas of Canadian strength, the Panel first looked at the number of Canadian patents as a share of world totals (as registered by the USPTO). To place these shares in context, the Panel examined Canada's relative share of

expenditures and patents. The U.S. National Science Foundation estimates that worldwide expenditure on all IR&D was US\$1.3 trillion in 2009, of which Canada accounted for slightly less than two per cent (NSB, 2012). Therefore, the Panel adopted the yardstick that if Canada held more than two per cent of the patents in a technology field, that technology would be identified as an area of relative strength for Canada.²⁸ Using the drugs example from above, this technology is an area of strength for Canada because Canada's three per cent share of drug patents is above the Panel's two per cent threshold.

The Panel used this approach to analyze the data presented in Table 3.2. The global rate of patenting at the USPTO is high in technologies linked to telecommunications equipment manufacturing; information and cultural services industries (e.g., multiplex communications, telecoms, data transferring, database management); and pharmaceuticals (e.g., drugs, molecular biology). In turn, Canada has a disproportionately large share of patenting in these fields, reaching double its overall share of global IR&D. Looking further down the top 50 list, Canadian patenting is also prolific in land vehicles, radiation imagery chemistry, and some data processing technologies. In contrast, Canada has a small share of the world's patent in active solid-state devices and semiconductor device manufacturing, although they are the third and fourth most patented fields worldwide. Other areas in which Canada does not apply for patents as much as other countries include business practices and electrical connectors.

Canada's strength in drug patents is confirmed by OECD analysis. The OECD has examined USPTO patent data on technologies specifically related to drug development (OECD, 2013). To simplify the technology classifications, the OECD grouped technology fields into more interpretable categories. The OECD data show relatively strong patent counts for various health-related technologies in Canada. On average, over the years 2003-2010, individuals and organizations in Canada were granted a total of 628 patents in these technologies: 232 patents in biotechnology, 161 patents in medical technology, and 220 patents in pharmaceuticals. By the end of this period, Canada was ranked fourth in biotechnology, seventh in medical technology, and sixth in pharmaceuticals. It is unclear whether all biotechnology-related patents are health related since such techniques may also be used in, for example, cleaning up waste or animal-related health.

28 A useful alternate approach would be to look at the stock of patents per technology field and the share of the stock held by Canada. Unfortunately, the data are not available in this format.

Table 3.2

Canadian Patenting Data for Top 50 Technology Fields Worldwide

Technology field	Patents issued for Canada, average 2007–2011	Canada's share of all patents issued in field (%)	Rank of fields, top 50 in Canada	Field's share of all patents (%)
Drugs	178.8	3.0	7	3.2
Multiplex communications	233.2	4.2	1	3.0
Active solid-state devices	22.8	0.4	45	2.9
Semiconductor device manufacturing	13.6	0.3	47	2.8
Telecoms	153.4	3.9	2	2.1
Multicomputer data transferring	110.0	3.1	5	1.9
Molecular biology and microbiology	85.2	2.7	10	1.7
Database and file management	94.4	3.1	4	1.6
Organic compounds	65.0	2.3	17	1.5
Image analysis	67.0	2.4	16	1.5
Computer graphics processing	81.8	2.9	9	1.5
Financial, business practice, management	46.4	1.8	25	1.4
Pulse or digital communications	68.8	2.7	11	1.4
Static information storage and retrieval	24.6	1.0	41	1.3
Synthetic resins or natural rubbers	38.2	1.6	29	1.3
Electricity: electrical systems and devices	31.2	1.4	34	1.2
Electrical connectors	16.6	0.8	42	1.2
Optical: systems and elements	26.4	1.2	38	1.2
Error detection/correction	34.2	1.6	30	1.2
Radiant energy	44.6	2.1	19	1.1
Stock material or miscellaneous articles	22.8	1.1	40	1.1
Surgery	40.2	2.0	20	1.1
Television	26.0	1.3	36	1.1
Communications: electrical	49.6	2.5	13	1.1
Support (electrical computers and digital processing systems)	50.4	2.6	12	1.1
Incremental printing of symbolic info.	6.6	0.3	46	1.0

continued on next page

Technology field	Patents issued for Canada, average 2007–2011	Canada's share of all patents issued in field (%)	Rank of fields, top 50 in Canada	Field's share of all patents (%)
Measuring and testing	33.6	1.8	24	1.0
Electricity: measuring and testing	28.2	1.6	31	1.0
Computer memory	28.0	1.6	28	0.9
Optics: measuring and testing	25.0	1.6	32	0.9
Facsimile and static presentation processing	7.0	0.5	44	0.8
Electrophotography	2.4	0.2	49	0.8
Measuring, calibrating, or testing	35.4	2.4	14	0.8
Vehicles, navigation, & relative location dp	21.6	1.5	33	0.8
Illumination	28.8	2.0	21	0.8
Surgery instruments	16.6	1.2	39	0.7
Optical waveguides	32.4	2.4	15	0.7
Liquid crystal cells, elements and systems	2.6	0.2	48	0.7
Internal-combustion engines	22.2	1.7	27	0.7
Presentation of documents	39.2	3.0	8	0.7
Land vehicles	44.6	3.4	3	0.7
Metal working	24.0	1.9	22	0.7
Miscellaneous active electrical nonlinear devices	16.8	1.3	35	0.7
Radiation imagery chemistry	36.8	3.0	6	0.7
Dynamic information storage or retrieval	0.4	0.0	50	0.7
Medicators and receptors	8.6	0.7	43	0.6
Electrical generator or motor structure	14.8	1.3	37	0.6
Chemistry: electrical apparatus	25.0	2.2	18	0.6
Cash registers, calculators, counting	20.8	1.9	23	0.6
Input/output (electrical systems)	19.6	1.8	26	0.6

Technology fields are ordered by total number of patents.

Data source: Panel analysis based on USPTO (2012)

The table shows that Canada is a leading developer of technologies linked to multiplex communications and drugs, which are also among the most patented fields worldwide. However, in other technology fields that show high rates of patenting worldwide (active solid-state devices and semiconductor device manufacturing), Canada's rate of patenting is low. This low rate probably reflects an absence of Canadian firms in these areas.

The rate of patenting at the USPTO may be lower in some technology fields because the pace of technology advance is not as rapid, new technologies can be kept secret, or the scale of IR&D is smaller. A degree of IR&D, however, is likely important for all businesses to maintain their competitive advantage. For example, well technologies in resource extraction is the 12th most patented field by Canadian firms at the USPTO, but the 44th most patented field by U.S. firms, and 64th by other firms. As a result, 1.1 per cent of patents issued to Canadian firms are in this field, but only 0.4 per cent of patents of other firms, suggesting this technology is an area of strength for Canadian firms.

Canada accounts for more than 10 per cent of the world's patent production in five technology fields: planting, wheel substitutes, earth working, fertilizers, and woodworking. Although these technologies represent only one per cent of Canada's total patent count during the 2003-2010 period, they are linked to prominent Canadian industries (e.g., agriculture, forestry, mining).

3.1.3 Number of Patents in Canada by Industry

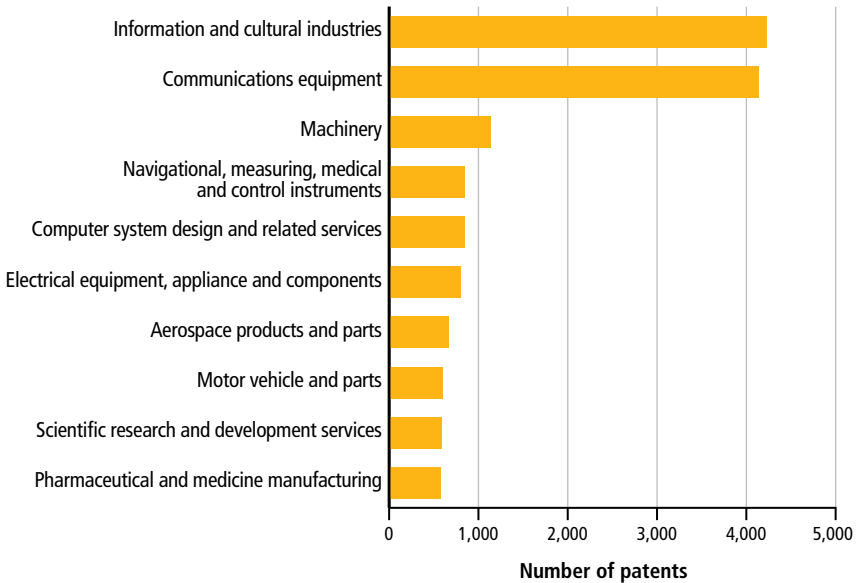
Patents for the technology fields discussed in the previous section were filed at the USPTO by a range of firms operating in a variety of industries. Unfortunately, it is not clear from which industry a patent originates although the data give a sense of where strengths lie. This problem arises because the data in a patent application form are not linked to the business register that forms the basis for statistical agencies' classification of firms by industry.²⁹

To address this issue and find out more about the industries involved in patenting in Canada, the Panel commissioned Science-Metrix to examine the Scopus database, which includes over 24 million patent records. On average, over 2,000 patents were granted annually to Canadian firms between 2003 and 2010, with just under 60 per cent granted to the manufacturing sector and about 40 per cent to the service sector. Other sectors accounted for the remaining 1 per cent. Ten industries in Canada accounted for 84 per cent of all of industrial patents granted in Canada (see Figure 3.3), and 57 per cent of all BERD over the period (recall Table 2.2). In turn, these 10 industries represented about 14 per cent of GDP, highlighting the disproportionate number of patents produced by a relatively small share of the economy. Together, information and cultural industries and communications equipment manufacturing accounted for half of Canada's patent output. The prominence of

29 A business is assigned a business number that streamlines how a company interacts with the government. Including this number on patent application forms would enable patent data to be linked to industry data in micro data files held by statistical agencies.

these industries is consistent with analysis of technology fields in the previous section, which suggested that technologies linked to communications had relatively high rates of patenting in Canada.

Of the 10 industries that patent most in Canada (Figure 3.3), a significant³⁰ increase in the rate of patenting occurred in aerospace, computer services, and motor vehicles from 2003 to 2010. In contrast, electrical equipment, and instruments, experienced significant falls over the same period.³¹ Outside the top 10, there were significant declines in patenting for agriculture, fabricated metal products, food, non-ferrous primary metals, semiconductors, retail, and other (non-electric) utilities over the period.



Data source: Calculated by Science-Metrix based on USPTO data

Figure 3.3

Industries with the Most Patents Granted, 2003–2010

The figure shows that information and cultural and communications equipment industries patent most in Canada. Collectively, the 10 industries shown here account for 84 per cent of Canada's patents.

30 In this section, “significant” indicates statistical significance. A simple regression was undertaken of patents granted on a time trend from 2003 to 2010. The trend coefficients were evaluated to determine whether the time trend was significantly different from zero using a two-tailed t-test.

31 Indeed, electrical equipment industry would have fallen out of the top 10 if the rankings were based on the number of patents issued in 2010, and instruments would have fallen to 10th. Computer equipment would have entered the top 10.

The majority of the 20 firms that patent most in Canada (see Table 3.3) are foreign owned, highlighting the contribution that foreign investment can make to knowledge creation in Canada. At least one-quarter of these firms are involved in communications equipment.

Table 3.3

Top 20 Firms in Canada by Patents Granted, 2003–2010

Company name	No. of patents	Company name	No. of patents
Nortel Networks Ltd.	2,538	Mold-Masters	157
Research In Motion	1,306	Mitel Corporation	156
Magna International	410	Sanofi	123
Pratt and Whitney Canada Corp.	397	Ballard Power Systems Inc.	119
Siemens AG	292	Eastman Kodak Company	92
Advanced Micro Devices Inc.	270	JDS Uniphase Corporation	85
MOSAID Technologies Incorporated	257	General Electric Co.	76
Husky Injection Molding Systems Ltd.	232	Nordion Inc.	73
Alcatel-Lucent	221	National Steel Car Limited	71
Bombardier Inc.	203	Tropic Networks, Inc.	71

Data source: Calculated by Science-Metrix analysis based on USPTO data

The table shows that a relatively small number of firms accounted for the bulk of Canada's patents.

3.1.4 Quality of Patents in Canada by Industry

To take into account the potential commercial failure of patents, researchers have developed indicators related to citations of pre-existing patents. A new idea is rarely completely novel; it usually relies on knowledge captured in existing patents. Thus the organization filing a patent application must reference existing patents on which the new patent builds. Since more important patents will be cited more often, patent citations can be used as an indicator of patent quality. Science-Metrix's method for implementing this strategy is outlined in Appendix A.

The average relative citation (ARC) score for Canada is 1.2, which means that patents from Canada are cited more often than the world average (the world's ARC is 1.0). (See Appendix A for how the ARC index is generated).³² The data

³² There are drawbacks to this approach. Since relatively few patents are heavily cited, data are not available or reliable for many industries. Furthermore, patent citations occur with a lag, so patent citations are not currently available for, say, 2009 and 2010.

show that patents from the Canadian manufacturing and services sectors are more highly cited than the world average, particularly in natural resource extraction (a sector that includes services related to resource extraction).³³ Table 3.4 shows the ARC scores for the 15 Canadian industries whose patents are cited at, or more heavily than, the world average. The rate of citation for finance, insurance, and real estate patents may reflect the inclusion of patent licensing firms in this industry.

Table 3.4
ARC for Patents by Industry in Canada, 2003–2010

Industry	ARC score	Industry	ARC score
Oil and gas extraction	2.9	Computer and peripheral equipment	1.3
Finance, insurance and real estate	2.4	Management, scientific and technical consulting services	1.2
Transportation and warehousing	2.1	Motor vehicle and parts	1.1
Information and cultural industries	2.1	Navigational, measuring, medical and control instruments	1.0
Communications equipment	2.0	Electrical equipment, appliance and components	1.0
Computer system design and related services	1.7	Pharmaceutical & medicine manufacturing	1.0
Semiconductor and other electronic components	1.7	Machinery	1.0
Other manufacturing industries	1.3		

Data source: Calculated by Science-Metrix based on USPTO data

The table shows the average relative citation (ARC) score for patents for those Canadian industries whose patents are cited at the world average (1.0) or above. Patents in several Canadian industries are heavily cited suggesting that the quality of IR&D in Canada is relatively high.

3.2 PUBLICATIONS

An area that has not been explored much to date is scientific publications by industrial researchers (Cincera & Dratwa, 2011). Since publications are part of “open science” (i.e., they contribute to the general body of knowledge rather than to a specific firm), it has not always been clear why profit-motivated firms should allow their researchers to publish findings. The high rate of publishing in industry, however, suggests that firms find it important for IR&D (Stephan, 1996). Firms may encourage research staff to publish their results as a means

³³ Patents from the construction sector are cited less than the world average. Insufficient data are available for patent citations from the agriculture and utilities sectors.

of retaining them or to recruit new researchers. Openness may also promote greater collaboration between business and universities. Publications can educate customers and differentiate firms from their competitors.

For all these reasons, the Panel decided to examine publications from industry as a relatively new indicator of IR&D activity. To address the absence of publication data, the Panel directed Science-Metrix to examine publication numbers recorded in the Scopus database to help determine how much IR&D activity is taking place in Canadian industries. Since more important articles tend to be cited more often, citation measures can provide an indicator of quality. The quality of the journals in which articles are published can also be measured as not all journals are of equal esteem. Although informative about IR&D in Canada, this analysis is limited by the lack of international comparisons because such data have not been collated internationally. Science-Metrix's methodology is laid out in detail in Appendix A.

Box 3.1

Scientific Publications by Researchers in Canadian Industry

Publication in scientific journals is not assumed to be a priority for industry-based researchers. Many researchers working in commercial settings, however, publish in scientific journals for their own professional development and as part of commercial strategies. According to Science-Metrix's analysis, 5.3 per cent of Canadian scientific publications between 2005 and 2010 had at least one author based in Canadian industry. In some fields of research, the contributions of industrial researchers are much higher. More than one-third of Canadian scientific publications relating to mining and metallurgy had at least one researcher based in the private sector. The table below lists fields in which Canadian industry researchers accounted for 10 per cent or more of Canadian scientific publications. In energy-related research, over 2,000 papers in this period were authored or co-authored by Canadian private-sector scientists or engineers. The table also identifies fields of science in which industry-based Canadian researchers are relatively highly cited. Bolded fields indicate where Canadian papers with industry-based authors have average citation levels of at least 25 per cent greater than the world average for that field (ARC score ≥ 1.25).

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Canadian Scientific Publications from Industry, 2005–2010

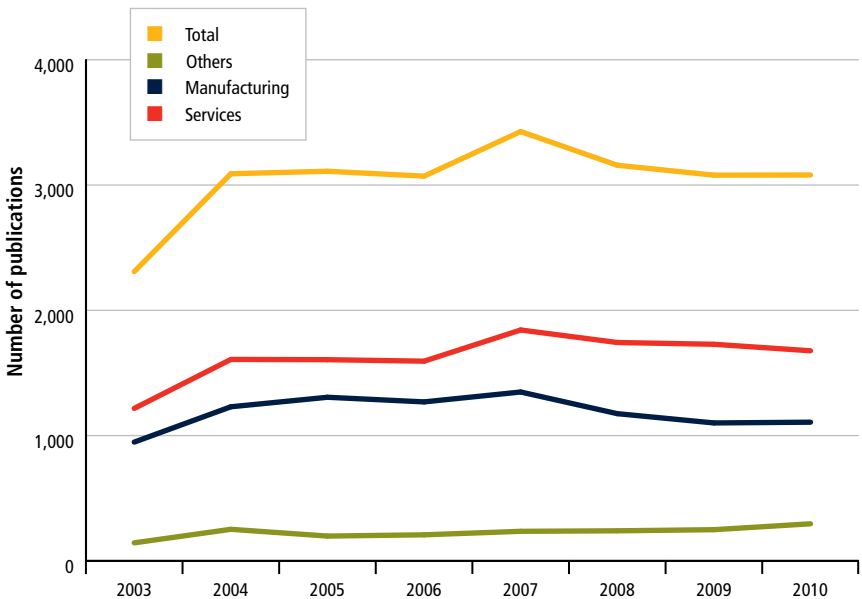
	Total Canadian Publications (2005–2010)	Industry Publications (2005–2010)	Industry as share of total (%)	Industry ARC
Mining & metallurgy	1,416	471	33.3	0.70
Energy	9,265	2,144	23.1	0.78
Medicinal & biomolecular chemistry	1,601	325	20.3	1.53
Geological & geomatics engineering	2,830	492	17.4	0.88
Civil engineering	2,961	504	17.0	0.65
Forestry	3,394	527	15.5	0.67
Optoelectronics & photonics	5,044	776	15.4	1.46
Strategic, defence & security studies	1,844	277	15.0	0.47
Materials	4,965	721	14.5	0.97
Environmental engineering	3,622	512	14.1	0.87
Building & construction	1,275	178	14.0	0.81
Mechanical engineering & transports	3,826	496	13.0	0.78
Geology	1,709	217	12.7	0.89
Applied physics	5,237	655	12.5	0.96
Chemical engineering	3,129	380	12.1	0.70
Dermatology & venereal diseases	1,044	126	12.1	3.75
Geochemistry & geophysics	4,067	490	12.0	0.81
Aerospace & aeronautics	1,776	204	11.5	0.92
Automobile design & engineering	944	105	11.1	1.49
Electrical & electronic engineering	4,876	537	11.0	1.56
Analytical chemistry	2,957	324	11.0	1.31
Computer hardware & architecture	1,034	103	10.0	1.04

Data source: Calculated by Science-Metrix based on data from Scopus (Elsevier)

3.2.1 Number of Publications in Canada by Industry

The total number of publications produced by all sectors combined in Canada is relatively constant at around 3,500 publications per year (see Figure 3.4). In contrast to the rates of patenting or BERD, the service sector accounted for the largest share, or just under one-half, of publications in Canada while manufacturing accounted for about one-third. Publications are possibly a more important indicator of research output in the service sector because they may be closer to the natural output of some service industries, and may even serve as a form of advertising. The large number of publications from the service sector has implications for understanding the relative research outputs of different industries.

The number of publications across industries varies widely. Some industries produced fewer than 10 publications between 2003 and 2010: beverages and tobacco, furniture and related products, other computer and electronic products, rubber products, and textiles. Together, the 12 industries with the largest number of publications consistently accounted for three-quarters of all publications over



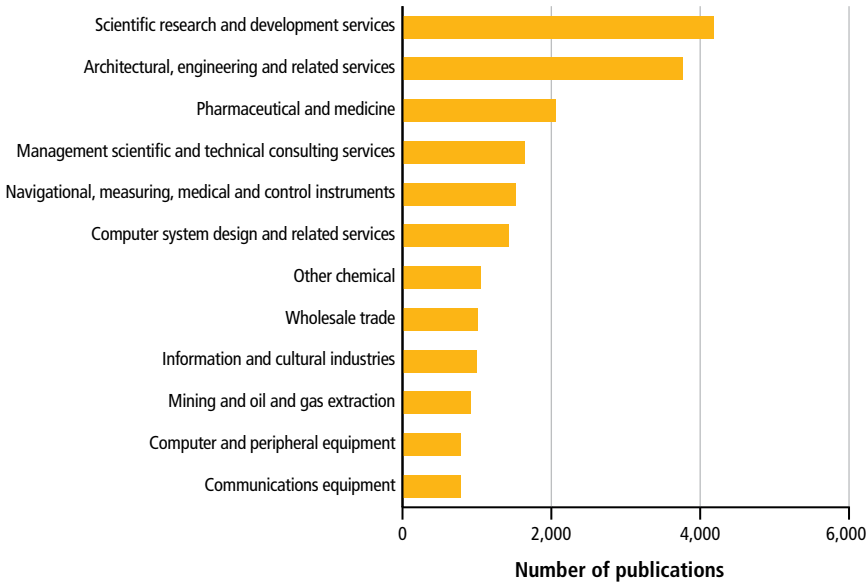
"Others" include agriculture, forestry, and fishing; mining, and oil and gas extraction; utilities; and construction.
Data source: Calculated by Science-Metrix based on Scopus (Elsevier) data

Figure 3.4

Number of Publications in Canada by Sector, 2003–2010

The figure shows trends in publications by sector in Canada. The service sector has a higher rate of publications than other sectors.

the period (see Figure 3.5 and Box 3.1). Seven of the 12 industries were in the service sector. Even in this grouping, however, scientific research and development services published five times more papers than communications equipment or computer and peripheral equipment.



Data source: Calculated by Science-Metrix based on Scopus (Elsevier) data

Figure 3.5

Industries in Canada with the Most Publications, 2003–2010

The figure shows that scientific R&D services and architectural, engineering & related services had the highest rates of publication. Publications may be an important indicator of IR&D output in the service sector.

Despite some deviations, the share of total publications of most industries remained constant throughout the period. This result is surprising given the potential for technological and structural change over time. The consistency may be a sign of the large adjustment costs involved in changing course once a business strategy to conduct IR&D has been established.³⁴ There were some exceptions to the trend. A statistically significant upswing in the rate of publications occurred in the oil and gas extraction and electric power industries. The rate also rose in the manufacturing sector, including in the other transport equipment, communications equipment, food, machinery, and printing industries. The rising number of publications in

³⁴ On the impacts of adjustment costs on R&D, see Bloom (2007).

the service sector was due to statistically significant increases in publications from architectural, engineering, and related services; computer system design and related services; and management, scientific, and technical consulting services. Collectively, these three service industries accounted for one-quarter of all publications between 2003 and 2010.

Publications in agriculture, semiconductor and other electronic components, and textiles showed a significant downward trend, which is broadly consistent with the trend in patenting. Total publications in the single digits in agriculture and textiles suggest that publications were not an important research output in these industries. The semiconductor industry, however, which had accounted for 1.8 per cent of Canada's publications in 2003, had its share halved by 2010.

3.2.2 Quality of Publications in Canada by Industry

The mark of a quality publication is that other researchers cite it in their research. The number of times a paper is cited can be linked to its influence. As with patents, an ARC score above 1.0 indicates that an industry performs better than the world average. The average quality of publications for most sectors of the Canadian economy is at or about at the world average (see Table 3.5). The data suggest that even if the amount of IR&D done in Canada is small relative to that in other countries, the quality is relatively high.

Table 3.5

ARC Score for Publications by Sector in Canada, 2003–2010

Sector	ARC Score	Sector	ARC Score
Agriculture, forestry, fishing & hunting	1.1	Construction	1.0
Mining and oil and gas extraction	0.8	Manufacturing	1.3
Utilities	0.6	Services	1.2
		Business sector	1.2

Data source: Calculated by Science-Metrix based on Scopus (Elsevier) data

The table shows the ARC score for publications from Canadian sectors. The ARC score for the manufacturing sector suggests its IR&D is of high quality.

Digging into the details reveals stronger pockets of research quality in Canada in a number of manufacturing and service industries (see Table 3.6). Taken together, Table 3.6 and Figure 3.5 (showing the quantity of publications by industry) suggest areas of strength in communications equipment, pharmaceutical and medicine, scientific research and development services, and information and cultural

industries. Each of these industries is in the top five for both quality and quantity of publications. Computer and peripheral equipment, wholesale trade, and other chemical industries also appear on both lists. Although not appearing on the list of top publication producers, all other transport equipment was identified as having rising research output, accounting for almost one per cent of all publications in 2007. The non-ferrous primary metal industry had highly cited output and accounted for about two per cent of publication output. In contrast, citations for publications in semiconductor and other electrical components suggest very high-quality research, but declining publication output.

Table 3.6

ARC Score for Industries with the Most Publication Citations in Canada, 2003–2010

Industry	ARC Score	Industry	ARC Score
Communications equipment	1.8	Primary metal (non-ferrous)	1.2
Semiconductor & other electronic components	1.8	All other transportation equipment	1.1
Pharmaceutical & medicine	1.6	Computer system design & related services	1.1
Scientific R&D services	1.6	Navigational, measuring, medical & control instruments	1.1
Information & cultural industries	1.5	Aerospace products & parts	1.0
Electrical equipment, appliance & components	1.5	Motor vehicle & parts	1.0
Computer & peripheral equipment	1.4	Management scientific & technical consulting services	1.0
Wholesale trade	1.3	Food	1.0
Other chemical	1.3	Mining	1.0

Data source: Calculated by Science-Metrix based on Scopus (Elsevier) data

The table shows industries with ARC scores of 1.0 and above. Industries linked to ICT and pharmaceuticals have particularly high ARC scores.

A further indicator of research quality is the impact factor, or the eminence, of the journals in which articles are published. The method of calculating the average relative impact factor (ARIF) is outlined in Appendix A.

The ARIF for Canada is 1.1, which means that Canadian publications are placed in higher-quality journals than the world average (of 1.0). Detailed industry breakdowns reveal that many of the industries with the highest ARIF scores (Table 3.7) also feature in the list of highest ARC scores (Table 3.6). Semiconductors

and communications equipment rank in the top two in both measures. Industries with a high ARC score but not included in the highest ARIF scores (Table 3.7) still have higher ARIF scores than the world average (e.g., electrical equipment, computers, wholesale and other chemicals).

Table 3.7

Industries with the Highest Publication ARIF Scores in Canada, 2003–2011

Industry	ARIF Score	Industry	ARIF Score
Semiconductor & other electronic components	1.5	Aerospace products & parts	1.2
Communications equipment	1.5	Scientific R&D services	1.2
Information & cultural industries	1.4	Computer & peripheral equipment	1.2
All other transportation equipment	1.4	Other chemical	1.2
Pharmaceutical & medicine	1.4	Wholesale trade	1.2
Motor vehicle & parts	1.3	Electrical equipment, appliance & components	1.2
Primary metal (non-ferrous)	1.2	Agriculture	1.2
Retail trade	1.2		

Data source: Calculated by Science-Metrix based on Scopus (Elsevier) data

The table shows industries with ARIF scores of 1.2 and above. ARIF is a measure of quality of publications. Publications from industries linked to ICT and pharmaceutical industries score highly.

3.3 CONCLUSION

The evidence presented in this chapter points to strong Canadian research output in some IR&D-intensive industries, such as communications equipment and pharmaceuticals, whose share of patents is above the world average. For example, by 2011, Canada had the sixth highest share of drug patents in the world. Despite a low rate of patenting in natural resources, Canada's high research output and quality by global standards likely help to maintain Canada's comparative advantage in these traditionally non-R&D-intensive industries. Although limited by the absence of international comparability, and the fact it is not necessary to undertake IR&D to produce a scientific publication, the data on publication output suggest significant research activity is occurring in several of Canada's service industries. The significance of publications as a means of research output in the service sector suggests that further research is required to understand this little-analyzed area.

4

Industrial R&D Outcomes: Innovation and Productivity

- **Innovation Survey Indicators**
- **International Expert Opinion Surveys**
- **Productivity as an Outcome of Innovation**
- **Exports as an Indicator of IR&D Strength**
- **Conclusion**

4 Industrial R&D Outcomes: Innovation and Productivity

Key Findings

- Since IR&D contributes to innovation, surveys of the propensity to innovate capture outcomes of IR&D as well as other sources of creativity. Innovation surveys have found that Canadian firms, on average, report a high propensity to innovate compared to their peers.
- Across industries, rates of product and process innovation are correlated with R&D intensity. Canada's most R&D-intensive industries tend also to report higher levels of product and process innovation.
- Data from two recent surveys of international researchers suggest that although Canada is not seen as a world leader in most areas of applied R&D activity, its contributions in certain areas, such as energy generation and efficiency technologies, are highly regarded.
- The shortfall in Canadian labour productivity growth rates relative to the United States appears to be particularly pronounced in R&D-intensive industries. It is possible that the smaller scale of these industries in Canada, rather than their R&D intensity, accounts for the shortfall.

The types of quantitative data reviewed in the preceding chapters show Canada's relatively weak overall performance in industrial R&D (IR&D) compared to peer countries, despite some specific areas of strength. Coupled with Canada's persistently low productivity, these kinds of indicators have led many to conclude that Canada underperforms compared to other countries when it comes to innovation (see Box 4.1). This chapter explores metrics that attempt to capture innovation more directly.

Statisticians' attempts to measure the outputs of IR&D have encountered significant challenges in recording and linking new products to IR&D activities. Innovation surveys have been developed in recognition that innovation inputs (such as IR&D expenditures) are only one factor among many driving innovation performance, and standard quantitative indicators related to IR&D outputs (such as patents) do not fully reflect either the relevant outcomes or impacts of these investments. In particular, measures such as patents do not capture process, marketing, or organizational innovations. These surveys are therefore a valuable reminder that innovation is much broader than introducing new products, and involves continual reassessment of production processes. Innovation surveys, which ask

firms to report on their innovation activities, gather quantitative data related to aspects of innovation that are not otherwise captured in existing data sources. These surveys, however, not only capture the outcomes of IR&D but also other activities that firms undertake to increase innovation. The results can sometimes require careful interpretation because respondents may understand the questions differently (Mairesse *et al.*, 2005).

Important research recognized by scientists and researchers around the world may also be underway in Canadian labs or institutions without yet yielding an impact that would register in existing quantitative metrics. It is thus instructive to examine the opinions of science, technology, and business leaders on Canada's IR&D strengths, particularly in emerging technologies.

This chapter also reviews evidence based on trends in productivity in Canada and on Canada's exports from high-technology industries. The focus of the evidence presented in this chapter is not *limited* to IR&D. None of these measures are confined to IR&D performance; rather, they are general measures that capture aspects of innovation or the outcomes of IR&D. Since innovation is a standard objective of investment in IR&D, these types of data remain relevant to the Panel's charge.

Box 4.1

Benchmarks of Canada's Innovation Performance

While the methodologies of some well-known international benchmarking exercises may be debated, they have contributed to the widespread consensus among policy-makers and observers that Canadian industry's innovation record is not as strong as its global peers (CCA, 2009; Industry Canada, 2011a; OECD, 2012a).

The Conference Board of Canada produces an annual report card on innovation as part of its broader *How Canada Performs* series (Conference Board of Canada, 2013). Based on an analysis of 16 countries and 21 innovation-related indicators, Canada has regularly received a "D" grade in innovation, putting the country at the bottom of its peer group. In the latest report, Australia, Austria, Belgium, Germany, and Norway also receive "D" grades. At the other end of the spectrum, Sweden, Switzerland and the United States receive an "A"; and the Denmark, Finland, the Netherlands, and the United Kingdom receive "B"s. In addition, retrospective analysis undertaken by the Conference Board suggests Canada would have received a "D" grade at least as far back as the 1980s.

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Innovation is 1 of the 12 pillars of the World Economic Forum (WEF)'s Global Competitiveness Index (WEF, 2012). Seven indicators of innovation are included in the Index, most of which are based on survey data from the WEF's executive opinion survey. The measures where Canada underperforms include firm capacity for innovation, company spending on IR&D, patent applications, and government procurement of advanced technologies. Canada ranked 14th overall in competitiveness out of all countries in the 2012–2013 assessment, down from 12th in 2011–2012.

4.1 INNOVATION SURVEY INDICATORS

As early as the late 1950s, innovation surveys were used to explore aspects of innovation not captured by standard quantitative indicators (Mairesse & Mohnen, 2010; Gault, 2010). The OECD formalized use of such surveys in 1992 with the publication of the *Oslo Manual*, which provides definitions for types of innovation and technical guidelines for countries undertaking innovation surveys (OECD/Eurostat, 2005). An important example of this type of survey is the Community Innovation Survey (CIS), which is undertaken periodically by a number of European countries, including all European Union member states. While the United States has not conducted such surveys in the past, their recent introduction may inform future analysis. Although not committed to a regular, periodic survey, Canada has carried out several such surveys, including sector-specific surveys in 1996, 1999, 2003, and 2005; and the broader Survey of Innovation and Business Strategy (Industry Canada, 2009, 2011b).

Innovation surveys can be used to present aggregated indicators of innovation performance across a variety of dimensions, including different types of innovation (product, process, marketing, and organizational) and other characteristics of innovative activities (e.g., degree of collaboration, firm investments in innovation). These surveys can be used to construct composite innovation indicators (such as the Innovation Union Scoreboard in Europe) and explore the determinants of innovation (Crépon *et al.*, 1998; OECD, 2009a; Therrien & Hanel, 2010; Mairesse & Mohnen, 2010). Past studies have found a positive relationship between IR&D effort and innovation outcomes (Mairesse & Mohnen, 2010).

The OECD (2009a) believes cross-country comparability of innovation surveys to be “good and improving,” and much of the data now provides informative, international comparisons of innovation activity. But, despite the OECD guidelines, methodological challenges inevitably limit use of innovation survey results in cross-country comparisons: differences in survey design and construction; sectoral

coverage; size thresholds (i.e., surveys focus only on firms above a certain size, which may differ across countries); length of reference periods; sampling frames; and units of analysis (OECD, 2009a).

4.1.1 Canada's Overall Innovation Activity

A core set of innovation survey questions asks firms if they have developed or introduced a new product, process, marketing, or organizational innovation in the relevant period. Canadian manufacturing firms report relatively high levels of innovation compared to their peers abroad. Around 81 per cent reported introducing some innovation in 2007–2009, and 70 per cent reported a product or process innovation (OECD, 2011a) (see Figure 4.1). Among countries for which the OECD collects data, only Germany had a higher share of manufacturing firms reporting the introduction or development of technological innovations. Canadian service firms also reported relatively high levels of innovation with 73 per cent reporting introduction of a product, process, marketing, or organizational innovation in the same period (see Figure 4.2). Canada ranks fourth on this measure, following Brazil, Iceland, and Germany, and well above the OECD average. Here, however, the share of firms that have introduced technological innovations (product and process innovations) drops to around 50 per cent. These results are consistent with the findings of previous innovation surveys (e.g., OECD, 2009a), and suggest that Canadian firms typically exhibit relatively high levels of innovation — particularly technological innovation in the manufacturing sector — when compared to firms in other countries.³⁵

In examining Canadian data, Hamdani and Bordt (2001) reported that 41 per cent of engineering firms identified themselves as innovators, but most of them introduced products that were duplications or replications of existing products with some modification: “Only 4 per cent of them had introduced breakthrough products or processes that had the potential of putting these firms in the role of global leaders.” A parallel finding, more in line with general views on Canada’s innovation performance, is that Canadian firms also report relatively low levels of “innovation sales” per employee in these surveys (Therrien & Hanel, 2010).

35 Canadian data are for firms with 20 or more employees. Data for European countries from the Community Innovation Survey often include firms with as few as 10 employees. The exclusion of these smaller firms from the Canadian data may be one factor in explaining Canada’s relatively high level of reported innovation.

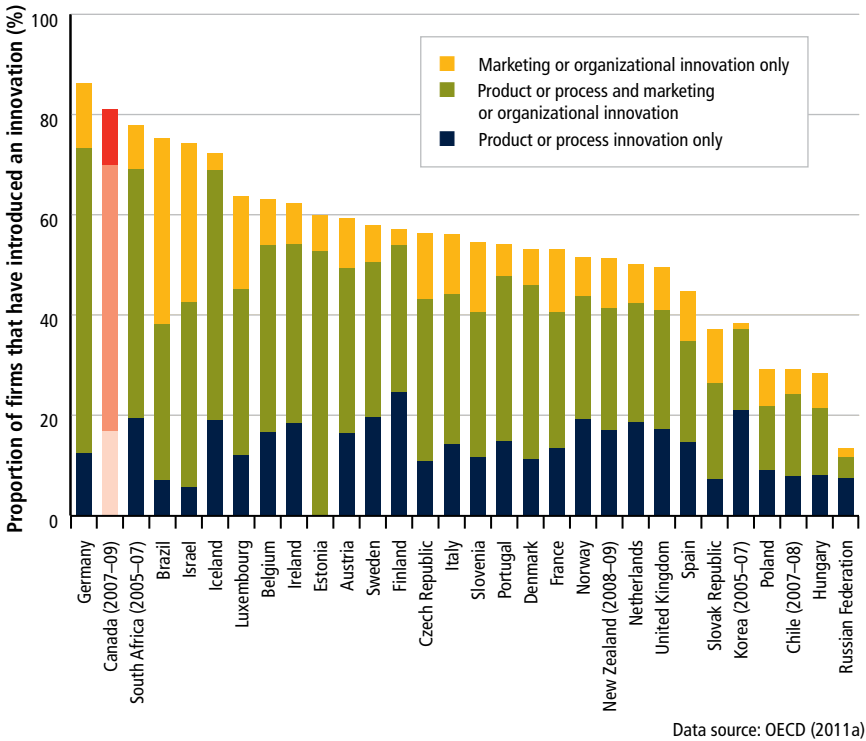


Figure 4.1
Innovation Status of Manufacturing Firms, 2006–2008

The figure shows the share of all manufacturing firms that have introduced marketing or organizational innovations, product or process and marketing or organizational innovations, and product or process innovations only. The underlying Canadian data used by the OECD are for 2007–2009, and are drawn from Industry Canada (2009). Canadian data are for firms with 20 or more employees whereas data for European firms are for firms with 10 or more employees.

4.1.2 Innovation Activity by Industry in Canada

Innovation surveys can also be used to analyze innovation activity and status across industries, though interpreting this information is more problematic due to the lack of relevant international benchmarks. According to the Canadian Survey of Innovation and Business Strategy (Industry Canada, 2009), between 2007 and 2009 roughly two-thirds of all firms in Canada introduced at least one type of innovation, whether a product, process, service, organizational, or marketing innovation (see Table 4.1). Manufacturing firms, on average, were more innovative than other firms. In many cases, different types of innovations occurred concurrently in a firm. For example, 60 per cent of all firms that introduced a product innovation and 27 per cent of those that introduced a process innovation

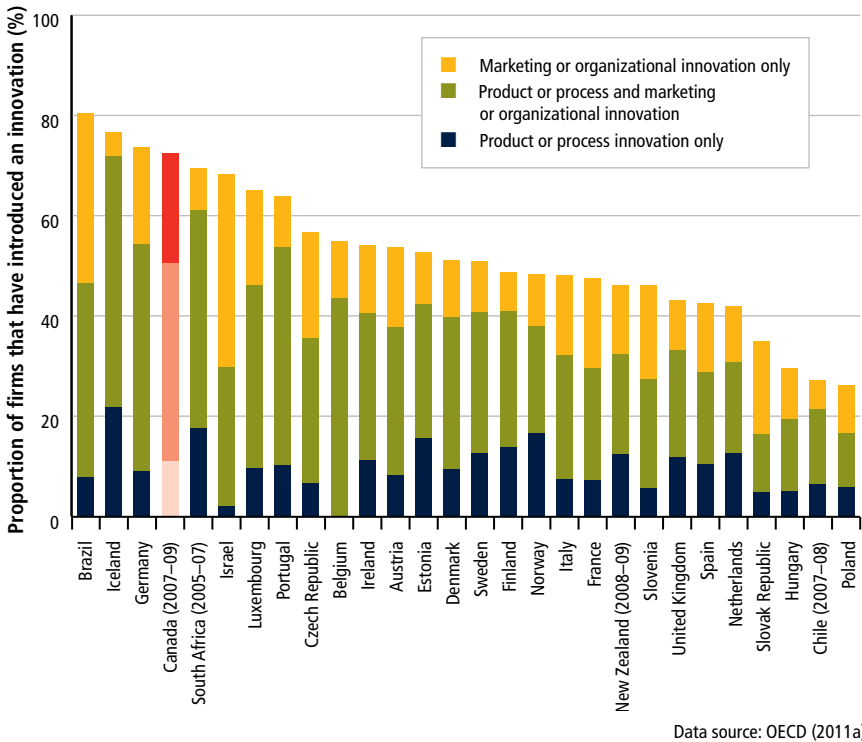


Figure 4.2

Innovation Status of Service Firms, 2006–2008

The figure shows the share of all service sector firms that have introduced marketing or organizational innovations, product or process & marketing or organizational innovations, and product or process innovations only. Canadian data are for the period 2007–2009, and drawn from Industry Canada (2009). Canadian data are for firms with 20 or more employees whereas data for European firms are for firms with 10 or more employees.

also reported a change in their marketing activities. Concurrent product and process innovation occurred in wireless communications carriers, communications equipment manufacturing, and aerospace products and parts.

High levels of product innovation are generally associated with technology-oriented industries in the manufacturing sector. For example, in Canada, communications equipment manufacturing reported the highest levels of product innovation, with 67 per cent of firms reporting the introduction or development of a new product. Computer and peripheral equipment manufacturing, navigational and control instruments, and plastic manufacturing also had high levels of reported product innovation, while retail trade, electric power generation, oil and gas extraction, and transportation and warehousing had low levels.

Table 4.1
Innovation Status by Industry in Canada, 2007–2009

Industry Sector	Percentage of Firms Reporting				
	Goods innovation	Service innovation	Process innovation	Organizational innovation	Marketing innovation
Total mining and oil and gas extraction	18.1	18.3	8	36.7	14.9
Oil and gas extraction, contract drilling and related services	6.4	0	8.7	20.9	2.9
Mining and related support activities	23.5	6.3	14.6	39.5	19.8
Utilities	11	16.6	14.3	32.3	17.1
Electric power generation, transmission and distribution	6.1	9	18.9	33.8	12.8
Construction	0	17.8	16.3	16.3	0
Manufacturing	42.6	21.7	15.7	44.9	20.4
Food manufacturing	36.5	14.4	17.7	38.3	20.2
Beverage and tobacco product manufacturing	55.9	21.6	26	38.8	21.8
Textiles	45.9	21.6	15.3	37.6	15.3
Wood product manufacturing	34.3	21.7	13.8	41.3	19.2
Paper manufacturing	33.8	17.8	15.4	53.4	9.8
Printing and related support activities	29.1	29.6	18.4	49.2	26.2
Petroleum and coal product manufacturing	50.1	11.6	11.6	46.2	15.3
Pharmaceutical and medicine manufacturing	59	25.8	27.1	60.5	29.9
Other chemicals	48.4	24.2	19.3	39.9	16.8
Plastic product manufacturing	59.9	35.1	13.6	52.6	27.1
Rubber product manufacturing	42.2	6.9	18.3	47.7	12
Non-metallic mineral product manufacturing	37.6	14.8	14	41.9	22.8
Primary metal (ferrous)	29.7	27.1	17.4	39.7	7
Primary metal (non-ferrous)	48.3	14.4	9.6	38	19.2
Fabricated metal product manufacturing	30	23.4	14.1	45.3	15.6
Machinery manufacturing	57.1	24.2	13.6	47	16
Computer and peripheral equipment manufacturing	65.3	50.6	30.1	41.4	34.1

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Industry Sector	Percentage of Firms Reporting				
	Goods innovation	Service innovation	Process innovation	Organizational innovation	Marketing innovation
Communications equipment manufacturing	67.6	38.4	23.5	53.7	27.2
Semiconductor and other electronic component manufacturing	58.9	26.5	27.8	58.8	38.4
Navigational, measuring, medical and control instrument manufacturing	62.2	22.9	11.7	71.7	32.3
Other computer and electronic products	52.7	22.5	15.2	62.2	19.5
Electrical equipment, appliance and component manufacturing	56.3	20.3	16.5	55.5	24.2
Motor vehicle and parts	44.4	22.2	27.8	61.1	38.9
Aerospace products and parts manufacturing	48.4	32.2	33.2	70.6	17.9
All other transportation equipment	43.8	25	18.8	43.8	25
Furniture and related product manufacturing	37.8	9.6	10.7	37.3	25.1
Other manufacturing industries	52.6	27.5	21.6	49.9	27
Total services	25.3	27.7	14.7	30.9	31.3
Wholesale trade	29.9	21	19.8	34	33.2
Retail trade	0.7		0	0	
Transportation and warehousing	8.7	29.1	24	23.7	16.3
Information and cultural industries	31.4	46.2	16.2	32	31.4
Finance, insurance and real estate	17.4	27	9	29.1	28.4
Architectural, engineering and related services	13.2	36.9	11.9	39.3	21.7
Computer systems design and related services	47.5	66.4	15.6	43.1	31.9
Management, scientific and technical consulting services	13.3	51.1	7.7	38.1	21.7
Scientific research and development services	41.1	39.5	10.4	45.7	23.9

Data source: Industry Canada (2009)

The table shows the percentage of firms by industry reporting the introduction or development of different types of innovation between 2007 and 2009. Cells are left blank where data were not of sufficient quality to be reported. See Industry Canada (2009) for more details on the survey methodology.

Process innovation patterns are similar. The highest levels of innovation were reported in technology-intensive industries, but with less overall variation. Aerospace had the highest level of reported process innovation in Canada, with 33 per cent of all firms reporting an innovation of this type over the period. Computer and peripheral equipment manufacturing, semiconductor manufacturing, and motor vehicle and parts manufacturing, also had high levels of reported process innovation, with low levels reported by management, scientific, and technical consulting services; mining and oil and gas extraction; and finance, insurance, and real estate.

Analyzing these patterns of reported innovation across industries provides useful insights into the types of firms that are dynamic when it comes to introducing new innovations or developing new products or services. Using this information to inform judgments about the relative strength of industries, however, is problematic without appropriate international benchmarks. Ideally, the performance of an industry in Canada would be compared to that of the same industry abroad. It would then be possible to construct such benchmarks with sufficiently extensive survey data from Canada and other countries.

4.2 INTERNATIONAL EXPERT OPINION SURVEYS

The Council recently undertook a large-scale survey of the world's top-cited researchers to inform a general assessment of Canada's science and technology (S&T) strengths (CCA, 2012a). The focus of the survey (and report) was academic, discovery-oriented research. With a few important exceptions, most fields and sub-fields included in the analysis are not directly relevant to the type of IR&D most likely to be occurring in industry labs and research facilities. Enabling and strategic technologies, information and communications technologies, and engineering, however, are relevant to the applied IR&D activities and technology development that often occur in the private sector. Table 4.2 presents the survey results for these research fields and sub-fields. It also shows Canada's overall rank relative to other countries in each field, and the percentage of respondents who identified that field as strong.

Table 4.2

International Opinion on Canada's Research and Technology Strengths

Field/Sub-Field	Canada's Rank	Percentage of Int. Survey Rating Field as Strong	Number of Respondents
Enabling & Strategic Technologies	8	59	226
Energy	4	72	17
Bioinformatics	5	46	35
Biotechnology	9	44	18
Materials	9	54	73
Nanoscience & Nanotechnology	11	66	56
Optoelectronics & Photonics	11	71	27
Information and Communications Technologies	6	70	414
Distributed Computing	2	76	18
Computation Theory & Mathematics	3	65	23
Information Systems	3	69	63
Medical Informatics	4	70	10
Artificial Intelligence & Image Processing	5	69	166
Computer Hardware & Architecture	5	67	13
Software Engineering	5	77	12
Networking & Telecommunications	6	71	108
Engineering	7	59	820
Operations Research	2	89	10
Geological & Geomatics Engineering	3	100	2
Civil Engineering	4	67	87
Chemical Engineering	5	55	86
Biomedical Engineering	6	69	44
Electrical & Electronic Engineering	6	58	233
Environmental Engineering	6	73	22
Mining & Metallurgy	6	62	47
Aerospace & Aeronautics	7	59	114
Industrial Engineering & Automation	7	45	27
Mechanical Engineering & Transports	7	52	144
Automobile Design & Engineering	9	33	4

Data in the table are not weighted by country of respondent.

Data source: CCA (2012a)

The table presents the results of a survey of the world's top one per cent of cited researchers. Column (2) shows Canada's rank against all other countries, in terms of the number of respondents who identified Canada as one of the top five countries in the world in that field; and column (3) provides the overall percentage of respondents by field identifying Canada's research in that area as strong (5 to 7 on a seven-point scale). Column (4) lists the number of survey respondents identifying that sub-field as their area of expertise. Fields with fewer than 30 respondents are coloured in red, and caution should be used when relying on these data.

Of the six areas of enabling or strategic technologies identified in the survey, Canada's performance was rated most highly in energy-related technologies, ranking fourth in the world. This rank is consistent with the opinions of Canadian S&T experts (surveyed in a separate study for the same Council assessment), who regard energy technologies as an area in which Canada is positioned to become a global leader (CCA, 2012a). Canada also ranks relatively highly in bioinformatics (fifth in the world), and is in the top 10 countries in biotechnology and materials sciences. Canada's efforts are well regarded internationally in many areas of information and communication technologies, including distributed computing (second in the world), computation theory and mathematics (third), information systems (third), and medical informatics (fourth). Some of these data should be interpreted with caution due to relatively low numbers of responses. Finally, Canada's research contributions are also well respected in areas of engineering: fourth in the world in civil engineering; fifth in chemical engineering; and sixth in biomedical engineering, electrical and electronic engineering, environmental engineering, and mining and metallurgy.³⁶

The annual survey of the global researcher community (university, business, and government researchers), undertaken by Battelle and R&D Magazine as part of its Global R&D Funding Forecast, is another source of data on international perceptions of technology strengths (Battelle, 2011). Canada is not recognized as a world leader (i.e., in the top five countries) in any of the 10 technology areas profiled in this survey (see Table 4.3). Canada ranks sixth, however, in energy generation and efficiency technologies, and is in the top 10 countries in agricultural and food production technologies, commercial aerospace, environmental and sustainability technologies, and health-care and medical science technologies. Although the identification of energy-related technologies is consistent with CCA (2012a) survey data, the R&D Magazine survey does not identify information and communication technologies as an area of strength for Canada.

36 Operations research and geological and geomatics engineering are not mentioned here due to low numbers of respondents, but could also be areas of Canadian strength if these responses are indicative of perceptions in the wider research community.

Table 4.3

R&D Magazine Survey Rankings of Countries by Technology Area

Technology Area	Top 5 Countries	Canada's Rank
Agriculture/food production technologies	U.S., China, Germany, Brazil, Japan	8
Automotive/other motor vehicle technologies	Japan, Germany, U.S., China, South Korea	Not in top 10
Commercial aerospace, rail, and other non-automotive transport technologies	U.S., China, France, Germany, Japan	8
Military aerospace, defense & security technologies	U.S., China, Russia, U.K., France	Not in top 10
Composite, nanotech, & other advanced materials technologies	U.S., Japan, Germany, China, U.K.	Not in top 10
Energy generation & efficiency technologies	U.S., Germany, China, Japan, U.K.	6
Environmental and sustainability technologies	Germany, U.S., Japan, U.K., China	7
Healthcare, medical, life science & biotechnologies	U.S., U.K., Germany, Japan, China	7
Information & communication technologies (ICT)	U.S., Japan, China, India, Germany	Not in top 10
Instruments & other non-ICT electronics technologies	U.S., Japan, Germany, China, U.K.	Not in top 10

Data source: Battelle (2011); data for Canada from special tabulation requested from R&D Magazine

The table shows Canada's rank by research/technology area in the 2012 Battelle and R&D Magazine Global R&D Forecast survey. Data are based on a survey of the global research community. The survey had 713 respondents from 63 countries. While the survey is not specific to industry, 39 per cent of all respondents were researchers based at corporations. Since ranking differences outside of the top 10 are not statistically significant, they are not listed.

Neither of these international opinion surveys is limited to IR&D activity. The results speak to broad areas of national research and technology strength, which may be distributed across academic and private-sector institutions and facilities. Nevertheless, the areas of research and technology development reviewed above often have direct connections to IR&D activity and development of commercial technologies. And, while survey data can be subject to a number of potential biases (CGA, 2012a), they can also complement quantitative data. In this case, international expert opinion appears broadly consistent with what might be inferred from quantitative indicators with the exception of information and communication technologies. Canada is not widely recognized as a world leader (i.e., in the top five countries) in most of these areas of applied R&D, though Canada's contributions are recognized and held in high regard in energy technologies and information and communication technologies.

4.3 PRODUCTIVITY AS AN OUTCOME OF INNOVATION

Through its role in promoting innovation, IR&D can aid productivity growth over the long term. Given that statisticians have developed independent measures of aggregate productivity, productivity (and multifactor productivity, MFP) is often discussed as a measure of innovation. MFP captures those drivers of productivity other than improvements in capital investments and the skills of the workforce. In practice, however, MFP is calculated as the residual, capturing any growth unexplained by either capital deepening or the addition of new labour. As such, it is often referred to as a “black box” or more famously as “a measure of our ignorance” (Abramovitz, 1956).

There is relatively little dispute that MFP, over the long term, captures important information about technological change and its role in driving efficiencies in economic production throughout the economy. Measuring productivity, however, is complex because of challenges involved in defining and measuring real inputs and outputs, and constructing appropriate price deflators (Baldwin & Gu, 2009; Diewert & Yu, 2012). Changes in MFP can also be driven by other factors such as economies of scale and efficiencies from the reallocation of production.³⁷

Because of the challenges in measuring MFP, it is more useful to compare labour productivity growth since these growth rates are less prone to methodological challenges. Almon and Tang (2011) calculated labour productivity growth rates for industries and sectors in both Canada and the United States. Table 4.4 shows the differences between the growth rates of the two countries. While, for example, labour productivity in the computer and electronics industry grew by 22 per cent per year in the United States between 2000 and 2008, it fell by 2 per cent per year in Canada. This difference reflects the 24.5 percentage point average annual gap shown in the table. Unfortunately, the industry classification is slightly more aggregated than that used in this report. As a result, communications equipment is included in the “computer and electronics” industry, for example.

The industries in which Canada is thought to have a traditional comparative advantage, such as primary metal manufacturing and mining, showed higher productivity growth in Canada. By contrast, the United States had higher productivity growth for IR&D-intensive industries such as computer and electronic products. Since Canada has relatively high IR&D intensity in some of these high-technology

37 Baldwin *et al.* (2008) compared the level differences of MFP between Canada and the United States. They concluded that the level of MFP was 89 per cent of the U.S. level in 2003 although their paper contains many caveats on the challenges of reconciling different national methodologies.

industries, it is possible that the productivity gap with the United States reflects the greater economies of scale available to these industries in the United States. These data also highlight that although IR&D can be a potent contributor to productivity, greater intensity of IR&D is not sufficient.

Table 4.4

Gaps in Labour Productivity Growth Rates, Canada and United States, 2000–2008

Industry/sector	Canada-U.S. gap (p.p.)	Industry/sector	Canada-U.S. gap (p.p.)
Computer & electronics	-24.5	Professional & business services	-1.5
Petroleum & coal products	-11.0	Arts, entertainment, & recreation	-1.3
Clothing	-10.7	Business sector	-1.2
Electrical equipment	-7.4	Utilities	-1.1
Information	-6.5	Services	-0.6
Transportation equipment	-5.6	Finance, insurance & real estate	-0.5
Textiles	-5.0	Food, beverage & tobacco	-0.4
Manufacturing	-4.5	Wholesale trade	0.1
Wood products	-4.3	Education, healthcare	0.3
Paper & printing	-3.7	Non-metallic mineral prods.	0.4
Chemicals	-3.2	Accommodation & food services	0.6
Furniture & misc. Manufacturing	-3.0	Agriculture, forestry, fishing & hunting	0.7
Administrative & waste management	-2.9	Mining	1.6
Plastics & rubber products	-2.8	Construction	1.9
Transportation & warehousing	-2.8	Retail trade	2.1
Oil & gas extraction	-2.7	Other services	2.4
Machinery	-2.0	Mining, excluding oil & gas	3.5
Fabricated metal products	-1.5	Primary metals	4.1

Percentage point (p.p.) differences in annual growth rates by sector (grey) and industry

Data source: Panel calculations based on Almon and Tang (2011)

The table shows the gap in labour productivity growth between Canadian and U.S. industries over the last decade. The reasons for the gaps are likely complex. The petroleum and coal products industry has invested heavily in machinery and equipment and there may be a lag before its productivity growth will increase. The gap in the IR&D-intensive computer and electronics industry may stem from the significantly larger U.S. industry, both in absolute and relative terms, and therefore in its capacity to reap economies of scale.

4.4 EXPORTS AS AN INDICATOR OF IR&D STRENGTH

Another indicator sometimes used to analyze IR&D strengths or capacity is exports of high-technology goods or services. Markets for high-technology products (and services, to a lesser extent) are often global, and research has suggested that higher levels of innovation are often associated with firms that export their products (OECD, 2009a). While exports and export shares are general economic performance indicators in that they are determined by numerous factors (e.g., market exchange rates, international trade agreements, global and local economic conditions), they also reflect patterns of comparative advantage.

Data from the World Bank (2012) suggest that high-technology exports play a relatively small role in Canadian exports as compared to other countries. In 2010, high-technology exports accounted for roughly 14 per cent of total manufacturing exports in Canada (see Figure 4.3). In comparison, high-technology exports accounted for 16 per cent of all manufacturing exports in the average OECD country, and 20 per cent or more in the United States, United Kingdom, and France.³⁸

Figure 4.4 uses OECD data on exports from industries that are typically IR&D intensive to plot Canada's share of global exports in 2000 and 2011 relative to Canada's share of total world merchandise exports. In 2011 Canada accounted for around 2.5 per cent of world exports (Foreign Affairs and International Trade, 2012). In contrast, in 2000 Canada only accounted for more than 2.5 per cent of world exports in the aerospace industry. After 2000 Canada's share of world exports dropped in all industries except pharmaceuticals. In 2011 Canada accounted for less than 1 per cent of world exports in electronics, and office machinery and computers, but its share of aerospace exports remained relatively high by international comparisons. Trends in export shares need to be interpreted in the context of growing outsourcing of production to developing economies and their increased shares of global markets.

Trade data can also be used on a more granular level to identify products or services in which Canadian firms appear to have an advantage (see Box 4.2). Unfortunately, relatively little of this analysis has been done for Canada to date. As a result, the only data available to inform the Panel's deliberations in this regard are the highly aggregated data collected by the OECD and reported above.

38 Manufacturing exports do not include unrefined petroleum products or natural gas, and therefore comparisons do not factor in the large share of Canadian exports accounted for by the oil and gas industry; if the comparisons were based on shares of total exports, Canada's share would be even smaller relative to its peers.

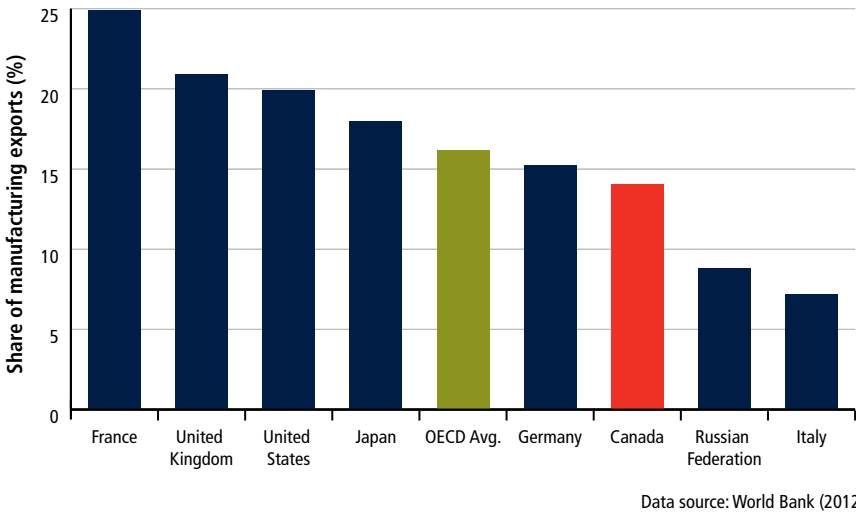
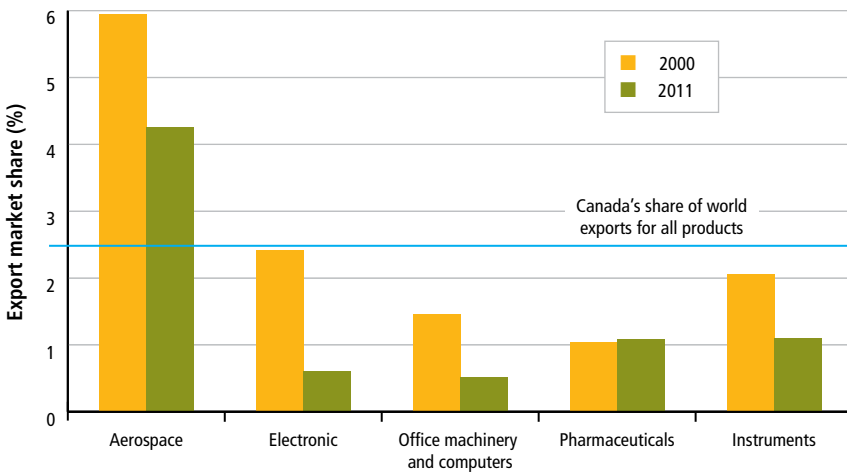


Figure 4.3

High-Technology Exports as a Percentage of Manufacturing Exports, 2010

High-technology exports are products with high IR&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.



Data source: OECD (2011b) and Canada's share of world exports are for merchandise exports in 2011, obtained from Foreign Affairs and International Trade Canada (2012).

Figure 4.4

Canada's Share of World Exports in Selected High-Technology Industries

The figure shows Canada's share of total world exports associated with five high-technology industries tracked by the OECD.

Box 4.2**Using Trade Data to Identify Technology Strengths**

Export and import data can be used at a more detailed level to identify technologies in which Canada has strength. For example, the Conference Board of Canada recently used this methodology to identify Canada's "revealed competitive advantage" for 40 "climate-friendly" technologies (i.e., technologies that help improve energy efficiency or generate energy with lower greenhouse gas emissions) (Conference Board of Canada, 2010). It compared the ratio of Canada's exports of a technology to total Canadian exports with the world's exports of that technology as a share of total world exports. The results suggest competitive advantages in areas where Canada "over-trades" or exports more of a technology than might be expected based on world averages.

The analysis identified Canada's relative strengths in technologies such as small gas turbines, landfill membranes, towers and lattice masts for wind turbines, hydraulic turbines, and photovoltaic system controllers. Canada exports more of these technologies than might be expected. For example, the share of gas turbines of less than five megawatts in Canada's total exports is nearly eight times higher than their share of total world exports.

The main limitation of this kind of methodology is that export patterns can be affected by many factors, such as trade barriers and other public policies, and are not necessarily driven by IR&D strengths. The approach does, however, provide a useful way of gauging the technological products in Canada that account for comparatively large shares of the world market. Further research of this type in Canada would enable future analyses to assess Canada's IR&D capacity on a more detailed level.

4.5 CONCLUSION

Most of the quantitative data available suggest that Canada underperforms its peers when it comes to innovation. Innovation is not synonymous with IR&D. IR&D is only one of many factors in the innovation process, and may be a relatively minor driver of many types of innovation (Miller & Côté, 2012). The ultimate objective of almost all IR&D, however, is innovation of some form, most often related to either the products (or services) a firm sells or the processes by which these products are generated and taken to market.

This chapter has reviewed certain strands of evidence that provide a different lens through which Canada's innovation performance might be viewed. First, innovation surveys have repeatedly found that Canadian firms report a greater propensity to innovate compared to their peers internationally. The full implications of this finding are unclear, and interpreting cross-country data drawn from disparate surveys invariably has its challenges. Innovation surveys do not report on the significance of the innovations.

Other survey data also contain useful insights on Canada's IR&D capacity. By and large, Canada is not widely regarded as a world leader in many areas of applied research or technology development. Both the survey of top-cited researchers in CCA (2012a) and the Battelle (2011) survey found that international experts rate Canada's research strength in energy generation and efficiency technologies relatively highly. In addition, the contributions of Canadian researchers appear highly regarded in a number of technology areas related to information and communication technologies and engineering. Again, while these are not necessarily strengths limited to IR&D, they are undeniably relevant to IR&D efforts.

Labour productivity growth is also, in some cases, used as a measure of innovation. The implications of changes in productivity across industries, however, are unclear for Canada. Evidence suggests that it would be incorrect to interpret declining or stagnant productivity as indicative of a lack of innovation in some sectors. As a result, the significance of productivity changes is difficult to interpret systematically. Nevertheless, relative to the United States, Canada's labour productivity growth is low across nearly all industries.

Finally, export data related to technology-intensive industries may also provide a valuable tool in analyzing national IR&D strengths. OECD data suggest that Canada accounts for a relatively large share of the world's aerospace market, and that Canada's share of world pharmaceutical exports has also been maintained over the past decade.

5

Regional Distribution of Industrial R&D in Canada

- **Local Benefits from Clusters of IR&D-intensive Firms**
- **IR&D Activity by Province**
- **Detailed Industry Performance by Province**
- **Quality Indicators of IR&D by Province**
- **Cities and IR&D**
- **Conclusion**

5 Regional Distribution of Industrial R&D in Canada

Key Findings

- Clustering is important in explaining patterns of IR&D expenditures. Firms tend to locate their R&D activities in the same geographic area to take advantage of knowledge spillovers, pools of skilled labour, and specialized suppliers and infrastructure.
- According to expenditure data, the majority of IR&D takes place in Ontario and Quebec. Some IR&D is also conducted in Alberta and British Columbia, particularly in industries related to natural resources.
- Patent and publication data also suggest that IR&D activity is concentrated in Ontario and Quebec but with niche areas of IR&D strength in other regions.
- Despite the powerful reasons why IR&D concentrates geographically in clusters, patent data suggest that IR&D is less concentrated in Canada than in many other countries.

In an interconnected world, ideas can flow freely across borders. The purchase of imported machinery and equipment embodying the latest technological breakthroughs from IR&D conducted abroad is essential to better business performance and productivity growth in Canada. New ideas and techniques can also be imported through foreign investment in Canada. Such openness to ideas from abroad is critical, as is development of new ideas from IR&D performed in Canada. In many cases, undertaking the IR&D in Canada means business needs in Canada are more likely to be met and, more importantly, significant local benefits are produced.

This chapter demonstrates the central importance of geography to understanding patterns of IR&D in Canada, a consistent finding in the extensive international literature on industry clustering and innovation. Firms engaged in IR&D tend to co-locate to benefit from knowledge spillovers, pools of talent, and specialized suppliers and infrastructure. These local assets collectively confer a competitive advantage to firms with ready access to them. Canada has many globally important clusters of IR&D-intensive firms. Geography and the intensity of knowledge activity clearly matter when looking at patterns of IR&D.

The Panel examined the geographic distribution of IR&D across Canada through Statistics Canada provincial data on IR&D expenditures and specialized workers, as well as data on publications and patents.³⁹ The analysis is limited in part by access restrictions to detailed IR&D expenditure data at sub-provincial levels. At this level, it relies instead on patent data that can be obtained for municipalities. As a result, the Panel struggled to identify and measure clusters from a Canadian perspective. Although important clusters have emerged across the country, the detailed IR&D data required to evaluate their success and impacts were not accessible. The patent data, however, do tend to support the importance of clustering in Canada.

5.1 LOCAL BENEFITS FROM CLUSTERS OF IR&D-INTENSIVE FIRMS

Clustering of similar firms in a small geographic area produces significant local benefits. Although applicable in many industries, the benefits of clusters appear to be particularly pronounced in R&D-intensive industries. The archetypal example is Silicon Valley: California accounted for 24 per cent of U.S. IR&D spending, but only 13 per cent of the economy in 2008 (NSF, 2013; Shackelford, 2012). Clusters can operate at an even more local level, with leading firms often locating within a few kilometres of each other. From around 1980 to 2000, the San Francisco Bay Area grew from accounting for 5 per cent of total U.S. patents to 12 per cent (Kerr, 2010).

Once created, clusters become a powerful magnet for investment and talent. As a former Apple executive explained: “The entire supply chain is in China now. You need a thousand rubber gaskets? That’s the factory next door. You need a million screws? That factory is a block away. You need that screw made a little bit different? It will take three hours” (Duhigg & Bradsher, 2012). Over time, workers absorb knowledge in one firm, move to another firm, and diffuse key ideas. Thus the strength of the cluster increases with the presence of a local pool of workers. These workers receive higher pay with each move, but their specialized skills are recognized only within the cluster.⁴⁰ Clusters are a powerful force to raise productivity where they occur.

39 The Institute of Competitiveness and Prosperity produces complementary data on clusters (ICP, 2013).

40 For evidence of spillovers between similar industries as a result of having more skilled workers together, see Moretti (2004). He also finds that this phenomenon then results in higher wages.

It has long been understood that clustering in an industry is driven by three key factors, each of which is particularly relevant to IR&D (Marshall, 1920):

- **Knowledge spillovers:** Spillovers from knowledge creation are not necessarily limited by national borders because knowledge, once created, can become available to all. However, since human contact (e.g., word of mouth, hands-on experience) is often needed to transmit these spillovers, it is beneficial for firms to locate together or close to universities. Not only is there scope for increased collaboration, but fierce competition also brings constructive feedback. Seeing cross-town rivals succeed can make entrepreneurs strive harder to beat their competitors.
- **Skilled labour:** Key individuals are important to setting up a cluster. Often, talented individuals congregate together, leading firms to also invest where skilled workers are available. Sometimes, a key individual attracts a team of workers that, over time, leaves to set up on its own close by, and the benefits snowball.⁴¹
- **Specialized suppliers and infrastructure:** Economies of scale mean that specialized infrastructure is developed so that the benefits of remaining close by are large. Niche service firms, whose only clients are research-intensive firms, may start up; in turn, the service firms may pull in other firms. For example, legal firms that specialize in venture capital financing are strong in Silicon Valley. Research laboratories, whether public or private, can provide valuable services to local firms.

Canada has many specialized and well-structured clusters. Despite the claims made for the benefits that clusters yield, their internal dynamics or impact on the economy are still not well understood and have not been analyzed nationally. Why they are established seems to be a matter of opportunistic initiatives from individuals, institutions, or industry leaders. They can often be the result of actions taken by particular individuals or events at a particular time in a particular place.⁴² For example, one impetus to the development of a telecommunications equipment cluster in Ottawa was the forced divestiture of Northern Electric from its U.S. owners in 1956 following a U.S. antitrust case (Wolfe, 2002).

Many claims have been made about the key catalysts for developing clusters and driving their growth, but understanding of them remains limited. There are many examples in Canada of successful clusters, but each has its own dynamic.

41 Zucker *et al.* (1998) found that, in the California biotech industry, spillovers came from having star scientists in a university faculty. Niosi and Queenton (2010) found similar results for Canada. See also Jaffe (1989), Jaffe *et al.* (1993), and Mansfield (1995).

42 More technically, Krugman (2009) stated: “Which location gets the concentration of production is arbitrary, and can be presumed to be a function of initial conditions or historical accident.” For a restrained evaluation of the state of knowledge around clustering, see Martin and Sunley (2003).

While the presence of universities and government laboratories has often been described as a key factor, Niosi and Zhegu (2005) concluded that universities and government laboratories played a limited role in building the aerospace cluster in Montréal; the presence of anchor firms was determined to be most critical. On the other hand, the presence of top-level universities and colleges around Waterloo has helped developed its ICT cluster (CCA, 2009, 2013). Saskatchewan has built up a strong biotechnology cluster around canola improvement and new product development (Smyth *et al.*, 2007). In examining key factors that contributed to this cluster, Phillips (2002) found the combination of local knowledge and openness to global knowledge was critical.

5.2 IR&D ACTIVITY BY PROVINCE

The distribution of IR&D across Canada largely reflects the distribution of population and economic activity (Table 5.1). The larger relative size of Ontario and Quebec means that more IR&D is performed in these provinces. Mining and oil and gas extraction account for a greater share of the economies of Newfoundland and Labrador, Saskatchewan, and Alberta (see Figure 5.1). Since more IR&D tends to take place in the manufacturing and service sectors, the IR&D intensity of resource-rich provinces tends to be lower.

In 2010 Ontario accounted for half of Canada's expenditures on manufacturing IR&D while expenditures on service IR&D were proportionately larger in Quebec and British Columbia (see Figure 5.1). Almost all of the IR&D expenditures related to mining and oil and gas extraction occurred in British Columbia and Alberta.

Ontario and Quebec represented 62 per cent of Canada's population and 58 per cent of Canada's GDP over the 2003-2008 period, but averaged 79 per cent of Canada's IR&D. As a result, Quebec had the highest IR&D intensity (1.75 per cent) followed by Ontario (1.56 per cent) (see panel B of Figure 5.2). While Ontario's IR&D intensity was similar to that of the average OECD economy (1.54 per cent), Quebec's IR&D intensity was on a par with IR&D-intensive economies such as Germany (1.78 per cent). Other provinces' IR&D intensities were below Canada's overall IR&D intensity, which averaged 1.1 per cent over the period.

Table 5.1
Provincial Distribution of IR&D by Sector, 2010

	Atlantic	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia	n/a
	Percentage							
Agriculture	8	29	37	4	5	3	14	0
Mining and oil & gas extraction	3	0	6	0	0	48	41	3
Utilities	1	0	31	1	0	0	0	67
Construction	2	0	44	0	2	0	0	52
Manufacturing	2	35	50	1	1	7	5	0
Services	2	31	46	2	1	6	13	0

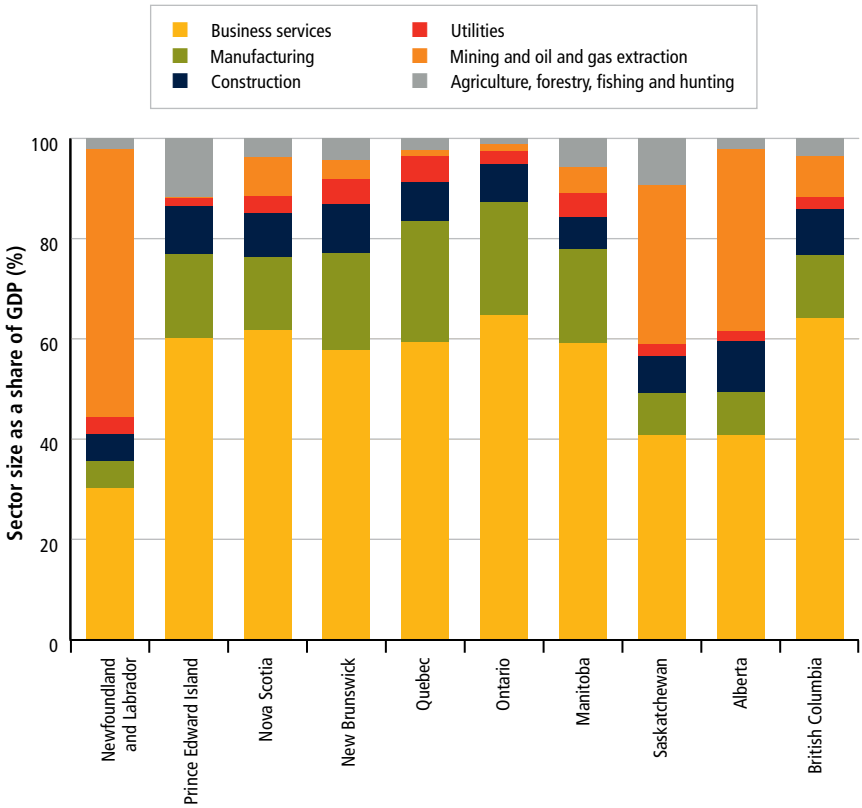
Some provincial IR&D data are suppressed to maintain confidentiality, and these expenditures are not assigned to provinces. These unallocated expenditures are reported in the final column as not allocated (n/a).

Data source: Panel analysis based on Statistics Canada (2012a)

The table shows that BERD tends to be geographically concentrated by sector. Most manufacturing and service sector R&D tends to take place in Ontario and Quebec, and most IR&D spending related to mining and oil and gas tends to take place in Alberta and British Columbia.

Similar to the pattern of IR&D spending, more than three-quarters of Canada's IR&D personnel are in Ontario and Quebec.⁴³ The average annual growth rate between 2003 and 2008, of 4 per cent, in the number of IR&D personnel in Canada was slightly ahead of the rates in Quebec, Nova Scotia, and Saskatchewan. Ontario's growth rate lagged at 3 per cent. (Statistics Canada, 2012a).

43 The distribution of IR&D researchers is slightly more concentrated than for all researchers. At the high end, 70 per cent of researchers in Quebec are in the industrial sector compared to just over one-third in Saskatchewan.

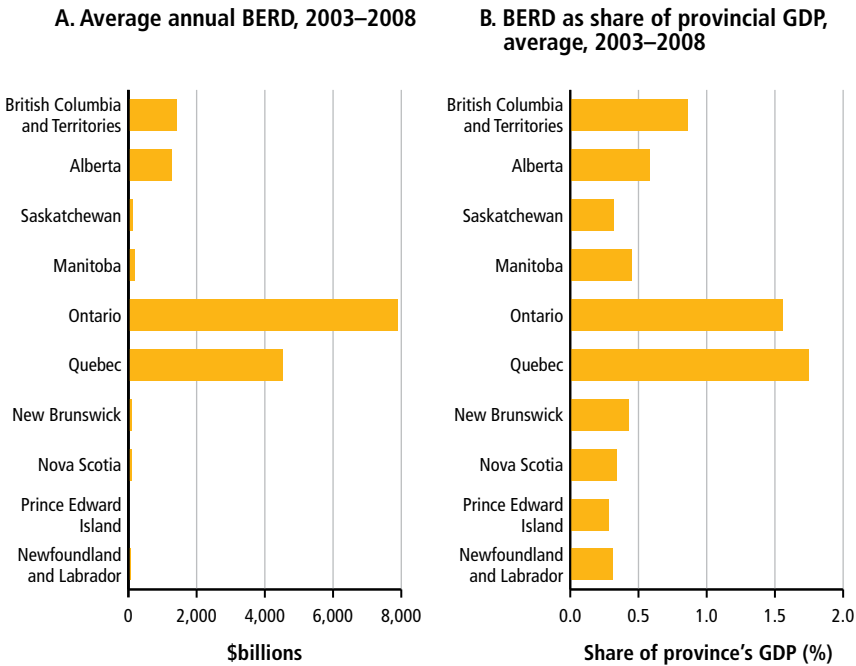


Data source: Panel analysis based on Statistics Canada (2013e)

Figure 5.1

Industrial Structure of Canadian Provinces, Average, 2003–2008

The figure shows differences in the sectoral makeup of Canadian provinces. While mining and oil and gas extraction are significant in Newfoundland and Labrador, Saskatchewan, and Alberta, manufacturing has a greater share of the economy in other provinces. IR&D tends to take place more in the manufacturing sector, and hence IR&D intensity tends to be higher in non-resource-intensive provinces.



BERD is in nominal dollars. Data are averaged.
Data source: Panel analysis based on Statistics Canada (2012a)

Figure 5.2

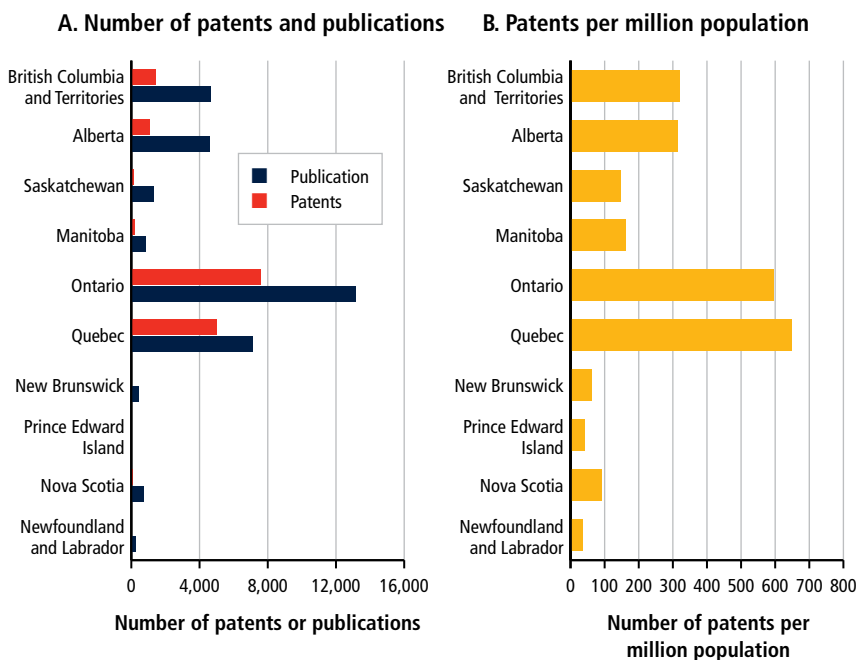
Provincial Distribution of BERD and IR&D Intensity, 2003–2008

Panel A shows that most BERD takes place in Ontario and Quebec. These are also the largest provinces in terms of economic size. Dividing BERD by the relative size of the provincial economies indicates IR&D intensity. Ontario and Quebec are highly IR&D intensive not only compared to other provinces but also compared to other countries.

Figure 5.3, panel A, shows the distribution of patents and publications across provinces. Of the patents whose origin can be traced to a province, more than three-quarters were granted to Ontario and Quebec.⁴⁴ In turn, Ontario and Quebec contributed about 60 per cent of total publications.⁴⁵ This pattern is the same after controlling for population. Panel B of Figure 5.3 shows that Quebec

⁴⁴ The origin of nine per cent of Canada's patents cannot be traced to a single province (e.g., they may have holders in multiple provinces).

⁴⁵ As discussed in Chapter 3, some problems with publication data cannot be avoided. Often, a publication can have multiple authors, each from a different province. The approach taken by Science-Metrix was to count each publication once if all authors were in the same province, but to count that publication for each province named if the authors were from different provinces. Although this necessarily implies double counting (see Table 5.3), the indicator is useful in that it signals where publication takes place.



Data source: Panel analysis based on Statistics Canada (2012a) and Science-Metrix analysis based on USPTO and Scopus (Elsevier) data

Figure 5.3

Provincial Distribution of Patents and Publications, 2003–2010

Although output measures indicate that IR&D is concentrated in Ontario and Quebec, publications data suggest a broader distribution of IR&D activity across all provinces. Ontario and Quebec produce more patents per million population than other provinces, although this may reflect the location of ICT industries, industries that traditionally have a high rate of patenting, in those provinces.

and Ontario still produce the largest number of patents, probably because the industries with high rates of patenting are located in these provinces. Although the values in Table 5.2 and Table 5.3 are not directly comparable because of double counting, the broader geographic pattern of publications in Table 5.3 suggests that IR&D is more geographically dispersed than suggested by IR&D expenditure data and patent counts.

Patent and publication data show geographic concentration (Table 5.2 and Table 5.3). Most of the patents developed in the manufacturing and service sectors are granted to firms in Ontario and Quebec. Alberta accounts for around one-half of the patents and publications in mining and oil and gas extraction.

Table 5.2
Provincial Share of Patents by Sector, 2003–2010

	Ontario	Quebec	Manitoba	Alberta	British Columbia
	Percentage				
Agriculture, forestry, fishing & hunting	55	20	20	0	5
Construction	55	25	0	3	9
Manufacturing	45	35	1	3	6
Mining and oil & gas extraction	19	2	0	58	15
Services	43	39	0	2	6
Utilities	35	10	0	5	50

Provinces who account for less than five per cent in all sectors are excluded from the table.

Data source: Science-Metrix analysis based on USPTO data

The table shows provincial production of patents by sector. Alberta accounts for more than half of patents in mining and oil and gas extraction, and Manitoba accounts for one-fifth of patents in agriculture, forestry, fishing, and hunting. In manufacturing and services, Ontario and Quebec account for around 80 per cent of patents.

Table 5.3
Provincial Share of Publications by Sector, 2003–2010

	Nova Scotia	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
	Percentage						
Agriculture, forestry, fishing & hunting	6	28	57	8	8	22	14
Mining and oil & gas extraction	1	5	31	1	7	45	14
Utilities	0	11	35	19	2	4	45
Construction	3	15	42	4	2	24	30
Manufacturing	3	30	51	2	3	14	15
Services	2	25	50	3	6	16	13

The table shows the number of publications produced in a province divided by the total number of publications for Canada. Publications often have co-authors from several provinces, and each author's publication is counted for their province. This methodology leads to double counting of publications with authors in multiple provinces and, as a result, percentages add up to more than 100 per cent. The table gives an indication of the relative weight of publications by province. Provinces who account for less than five per cent in all sectors are excluded.

Data Source: Science-Metrix analysis based on Scopus (Elsevier)

The table shows the provinces that produce publications for major sectors of the economy. The pattern of publications is more evenly distributed than for patents. Nevertheless, Ontario and Quebec account for the majority of publications.

5.3 DETAILED INDUSTRY PERFORMANCE BY PROVINCE

Identifying strength in IR&D requires analysis of industry performance in each province. Industry breakdowns are only meaningful within the manufacturing and service sectors. Table 5.4 presents a snapshot of the geographies where the scale of IR&D is disproportionate to a province's relative economic size in Canada. The Panel examined the data on BERD, patents, and publications to determine if any of these indicators represented a greater share of Canada's total GDP than a province's share of Canada's GDP. An asterisk was assigned in the table for each indicator that satisfied this criterion. For example, pharmaceutical manufacturing in Ontario has three asterisks for its higher share of Canada's BERD, patents, and publications than Ontario's nearly 40 per cent share of the Canadian economy would suggest.

Table 5.4 suggests that IR&D is concentrated in Ontario and, to a lesser extent, Quebec, which has a greater concentration of IR&D in wood, paper, aerospace, and other transport equipment industries. Exceptions of note include paper and semiconductor industries in British Columbia, and the food industry in Atlantic Canada (principally New Brunswick).⁴⁶ Ontario and Quebec are dominant in service sector industries, with Alberta strong in transportation and warehousing services, and British Columbia strong in retail, management, scientific and technical service, and scientific research and development service industries.⁴⁷

5.4 QUALITY INDICATORS OF IR&D BY PROVINCE

5.4.1 Quality of Patents by Industry

The ARC score provides an indicator of the quality of patents. The low number of patents produced for many industries in some provinces means meaningful ARC scores cannot be generated. A high ARC score, however, is a powerful signal of both the quantity and quality of a province's patents. These metrics point to eight industries with marked research strength in manufacturing (see Table 5.5), of which Ontario's research quality is significantly above average in six of them. Research quality is very high for the semiconductor and computer industries in British Columbia. Canada's high ARC score for communications equipment comes from Ontario and Quebec.⁴⁸

46 Expenditure data for Atlantic Canada are aggregated, but patent and publication data are available on a provincial basis.

47 The transportation and warehousing industry includes firms owning pipelines for distributing oil and gas.

48 Outside of the manufacturing and service sectors, the stand-out ARC score is 3.1 for patents from the mining and oil and gas extraction sector in Alberta, and from utilities in Nova Scotia. However, these ARC scores refer to a small number of patents. Detailed industry data show that the high ARC score for the mining and oil and gas extraction sector in Alberta is concentrated in the oil and gas extraction industry, which has an ARC score of 3.0.

Table 5.4

Provincial IR&D Activity by Manufacturing and Service Industry, 2003–2008

	Atlantic	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
Food	***	**	**	*	**		
Beverage & tobacco products		**	**				
Textiles		**	***				
Wood products	*	**	*				***
Paper	*	***				**	**
Printing & related support		**	**	*			*
Petroleum & coal products	*		*			**	**
Pharmaceutical & medicine		***	***				**
Other chemical	*	**	***		*	**	*
Plastic product		**	***	*		*	
Rubber products		**	**			*	
Non-metallic mineral products	*	**	**				
Primary metal products		***	***		*	**	**
Fabricated metal products	*	*	***		*	**	*
Machinery		**	***	*	*		*
Computer & peripheral equipment		*	***			*	*
Communications equipment		**	***			*	
Semiconductor & other electronic component		*	***				***
Navigational, measuring, medical & control instrument		**	***			*	
Other computer & electronic products		*	***				*
Electrical equipment, appliance & component		**	***				**

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	Atlantic	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
Motor vehicle & parts		*	***	**		*	*
Aerospace products & parts		***	*				*
All other transport equipment		***	*			*	
Furniture & related product		**	***	*		*	
Other manufacturing		***	**				*
Wholesale trade		**	***			*	
Retail trade		**	**				***
Transportation & warehousing			**			***	*
Information & cultural industries		***	***			*	*
Finance, insurance, & real estate		**	***				*
Architectural, engineering & related		**	**			*	*
Computer systems design & related		**	***			*	
Management, scientific & technical consulting		*	***			*	***
Scientific R&D		***	*	*		*	**
Other services	*	***	***			*	

An asterisk was assigned when a province had a higher share of business enterprise expenditure on IR&D (BERD), patents, or publications than its share of Canada's GDP. An asterisk was assigned to Atlantic Canada when any of its provinces had a higher share of patents and publications.

Data source: Panel analysis based on Statistics Canada (2012a) and Science-Metrix analysis of Scopus (Elsevier) and USPTO data.

The table summarizes the relative size of a number of indicators of IR&D strength by province. Outside of Ontario and Quebec, the data suggest, for example, areas of IR&D strength in other provinces, such as food manufacturing in the Atlantic Provinces and wood and semiconductor manufacturing in British Columbia.

Table 5.5

Provincial ARC Scores (1.0 and above) for Patents by Industry, 2003–2010

	Canada	Quebec	Ontario	Alberta	British Columbia
Communications equipment	2.0	2.3	1.3		
Computer & peripheral equipment	1.3		1.2		1.8
Electrical equipment, appliance & components	1.0				1.3
Machinery	1.0			2.4	1.0
Navigational, measuring, medical & control instruments	1.0	1.7	1.0		
Pharmaceutical & medicine	1.0		1.9		
Other manufacturing industries	1.3	1.6	1.5		
Semiconductor & other electronic components	1.7		1.7		2.2
Computer system design & related services	1.7	1.1	1.7		2.5
Finance, insurance & real estate	2.4		2.0		
Information & cultural industries	2.1	2.2	1.6		
Management scientific & technical consulting services	1.2		1.5		1.2
Transportation & warehousing	2.1		1.2		
Wholesale trade				3.6	

Data source: Science-Metrix analysis based on USPTO data

The table shows the provincial ARC score for patents by industry. The data suggest, for example, the quality of patents is high for communications equipment and information & cultural industries in Quebec, semiconductors and computer services in British Columbia, and machinery in Alberta. Even if IR&D for Canada as a whole does not rank highly, there are pockets of strength, such as for machinery in Alberta.

5.4.2 Quality of Publications by Industry

Average relative citations for Canadian publications have also been calculated. Citations to publications in the manufacturing sector are high, and publication quality appears to be above average, particularly in British Columbia and Manitoba (although their output quantity does not match that of Ontario). Publication quality appears to be high in the service sector in Nova Scotia and Manitoba.⁴⁹

⁴⁹ Again, outside of manufacturing and services the number of publications is relatively low, and hence the ARC score is not as informative.

Table 5.6 looks at ARC scores for those industries and provinces that stand out (ARC scores of 1.0 or above) and for Canada as a whole. Canada's strong performance in semiconductors appears to come from Ontario, Quebec, and, particularly, British Columbia; and in communications equipment from Ontario and Quebec. Canada's publication strength in pharmaceuticals is distributed across the country. In the service sector, Canada's citation rate for publications in scientific research and development services appears to be distributed across the country as it is largely for wholesale trade. Publication strength in information and cultural industries comes from Ontario and Alberta.

Table 5.6

Provincial ARC Scores (1.0 and above) for Publications by Industry, 2003–2010

	Canada	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Nova Scotia
Aerospace products & parts	1.0	1.4				1.0	1.3	
All other transportation equipment	1.1		2.0				1.1	
Communications equipment	1.8					2.0	1.3	
Computer & peripheral equipment	1.4	1.6				1.4	1.6	
Electrical equipment, appliance & components	1.5	2.4	1.2			1.2	1.4	
Navigational, measuring, medical & control instruments	1.1	1.2				1.2	1.1	1.4
Non-metallic mineral products						1.2		
Other chemical	1.1	1.2	1.0				1.4	
Pharmaceutical & medicine	1.6	1.9	1.6	1.7	1.1	1.6	1.6	1.2
Primary metal (non-ferrous)	1.2	1.5				1.4	1.1	
Semiconductor & other electronic components	1.8	2.8				1.7	1.5	
All other services		1.2	1.0	1.4			1.4	
Architectural, engineering & related services		1.0		1.3	1.1		1.1	1.3
Computer system design & related services	1.1	1.0				1.3		

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	Canada	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	Nova Scotia
Finance, insurance & real estate								
Health care & social assistance								
Information & cultural industries	1.5		1.9			1.6	1.1	
Management scientific & technical consulting services	1.0	1.1	1.0	1.0	1.0		1.0	
Retail trade								
Scientific R&D services	1.6	2.0	1.3	1.1	2.8	2.2	1.3	2.8
Transportation & warehousing								
Wholesale trade	1.3	1.5				1.7	1.6	

Data source: Science-Metrix analysis based on data from Scopus (Elsevier)

The table shows ARC scores for industries by province. The data indicate that there are areas of quality in IR&D across Canada.

5.5 CITIES AND IR&D

Firms undertaking similar activities will not only locate in the same province as their competitors, suppliers, and labour pool, but also within a few kilometres of each other. Unfortunately, fewer data are available at this level.⁵⁰ Aharonson *et al.* (2008) had to resort to linking their data to postal codes to examine Canadian biotechnology firms across Canada. They concluded: “Our results indicate that agglomeration effects do not take place at province, regional or even metropolitan levels, but rather at the level of local neighborhoods.” But even this finding is likely to be complicated by differences across industries.

IR&D is likely to take place within and close to cities. Cities are sources of important services such as patent lawyers and transportation, and also attract innovative people seeking a stimulating environment. Glaeser and Resseger (2009) argue for a strong correlation between worker productivity and metropolitan

50 For some discussion of the state of data on clusters in Canada, see Davis *et al.* (2006).

area population when the level of skills is high. Their results suggest that more spillovers occur in cities, and hence technological change is faster. Cities with high skill levels can grow and attract more skilled workers.

Baldwin *et al.* (2010) examined the effect of clustering (without identifying clusters) in Canada using plant-level data for manufacturing firms. The three elements highlighted above are important: buyer-supplier networks; labour-market matching (having people in the occupations needed by industry); and spillovers occurring within, not across, industries. Spillovers are highly localized to the extent that they fall away after a distance of five kilometres.

The OECD has started to develop indicators of patenting at a local level (OECD, 2008b).⁵¹ The patent data available reflect all patents granted, including those for universities and government. Comparing regional performance is not always straightforward because the definition of a geographic area varies across countries, such as by the number of people and geographic size. Beneficial agglomeration effects from attracting more talent may increase with city size so global megacities captured as one observation in the data may undertake a disproportionate share of the world's IR&D.⁵²

Concentration of IR&D appears to take place in Canada as well. The Greater Toronto Area (GTA) produces almost as many patents as Vancouver and Montréal combined (see Table 5.7) while no patents at all are filed for 100 of Canada's 286 regions (see Figure 5.4).⁵³ The number of patents per capita is higher in Ottawa–Carleton and Waterloo, probably reflecting the greater propensity to patent in the ICT industries. A similar finding was reported in Niosi and Bourassa (2007). They had obtained specially tabulated data from Statistics Canada that reported BERD by census area.

51 These data cover Patent Cooperation Treaty patents.

52 On the impact of city size on agglomeration effects, see, for example, Behrens *et al.* (2012).

53 Census division is the general term used by Statistics Canada for provincially legislated areas (such as county, municipalité régionale de comté, and regional district) or their equivalents. Census divisions are intermediate geographic areas between the province/territory level and the municipality (census subdivision). See Statistics Canada (2012c).

Table 5.7

Total Patents Issued for the 10 Regions that Patent Most in Canada, 2008

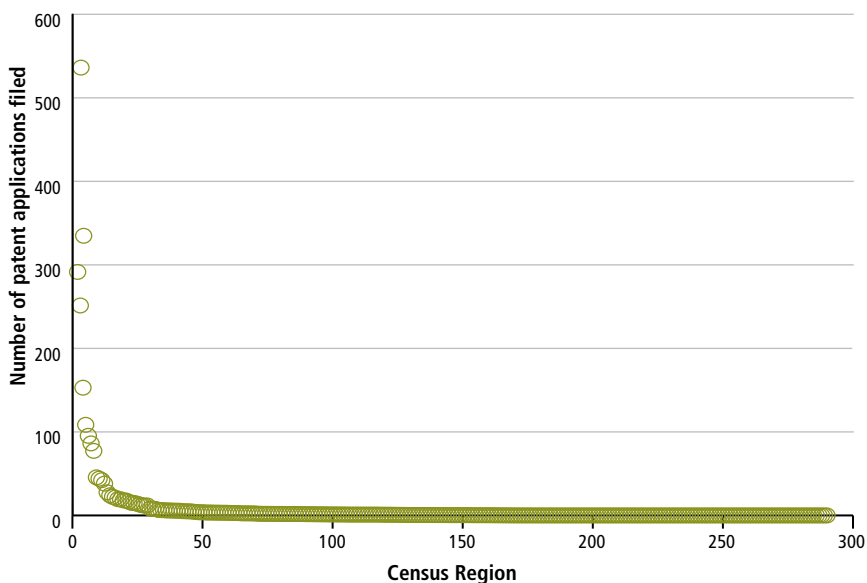
		Total no. of patents	Share of Canada's total patents (%)	Patents per million population
1	Greater Toronto, ON	536.2	20.6	96.9
2	Montréal, QC	334.8	12.9	88.9
3	Greater Vancouver, BC	291.5	11.2	127.9
4	Ottawa–Carleton, ON	251.3	9.7	209.3
5	Calgary, AB	153.0	5.9	128.7
6	Québec, QC	108.5	4.2	147.0
7	Waterloo, ON	95.3	3.7	197.8
8	Edmonton, AB	86.2	3.5	76.4
9	Middlesex, ON	45.6	1.8	94.1
10	Champlain, QC	42.2	1.6	292.3

The OECD provides data for patents issued for Metro Toronto, York, Peel, Halton, and Durham, which are combined to produce the total for Greater Toronto. Montréal includes Laval. Champlain includes the Trois-Rivières metropolitan area.

Data Source: Panel analysis based on OECD (2013), Statistics Canada (2013f)

The table shows that most patents are produced in Canada's large cities. One-half of Canada's patents are produced in Toronto, Montréal, Vancouver, and Ottawa. The high rate of patents created per capita in Ottawa and Waterloo probably indicates the importance of ICT-related industries in these cities, which traditionally have a high rate of patenting.

The data gathered by the OECD can also be used for cross-country comparisons of the differences in patterns of geographic distribution in a country (OECD, 2013). For example, the GTA accounted for 20 per cent of Canada's total in 2008. In the United States, the highest rate of patenting occurred in the Silicon Valley and New York regions, which produced 5,544 and 3,576 patents or 13 and 8 per cent of U.S. totals. By contrast, other economies, and particularly smaller economies, tend to have much more concentrated geographic patenting. Tokyo produced 8,486 patents or 33 per cent of Japan's total patents, Stockholm produced 1,118 patents or over a third of Sweden's total, the Eindhoven region produced 1,865 patents or just over 50 per cent of the Netherlands' total, and the Helsinki region produced 689 patents or 45 per cent of Finland's total (OECD, 2012c). This concentration of patenting in a limited number of cities in non-North American countries may cast some light on how small economies can reap economies of scale to improve their IR&D performance.



Census regions are numbered arbitrarily from 1 to 285. The OECD was unable to allocate 77 patents.
Data source: OECD (2013)

Figure 5.4

Number of Patent Applications Filed by Census Region in Canada, 2008

The figure shows that the production of patents is concentrated in a few cities. The vast majority of census regions in Canada produce no patents. This pattern of geographic concentration is reflected in other countries.

Table 5.8 shows the five regions around the world that accounted for most of the patents in ICT and biotechnology in 2009.⁵⁴ It also shows the number of patents produced by the five highest ranked Canadian cities or regions. Again, the production of patents is highly concentrated in other countries. Cities such as Tokyo (Japan), Shenzhen (China), and Gyeonggi-do (Korea) produce large numbers of patents, and between one-third and two-thirds of their countries' patents in ICT. In contrast, ICT patent production in the United States and Canada is more geographically dispersed. The same pattern holds for biotechnology patents, but the total number of patents produced in other countries is much lower than in the United States: Tokyo accounts for nearly one-quarter of Japanese patents, Rotterdam accounts for nearly two-thirds of Dutch patents, and Melbourne accounts for nearly two-thirds of Australian patents.

54 The OECD also produces such data for nanotechnologies and green technologies, but the scale of patent production is much smaller.

Table 5.8
Patents for Selected Technologies, by Region, 2009

ICT Patents				Biotechnology Patents			
Rank	Region and country or province	Number of patents	Share of country total (%)	Rank	Region and country or province	Number of patents	Share of country total (%)
1	Tokyo, Japan	4535	38.6	1	Boston-Worcester-Manchester, U.S.	517.6	13.3
2	San Jose-San Francisco-Oakland, U.S.	3118	21.6	2	San Jose-San Francisco-Oakland, U.S.	507.3	13.0
3	Shenzhen-Guangdong, China	2811	60.6	3	New York-Newark-Bridgeport, U.S.	320.6	8.2
4	Gyeonggi-do, Korea	1638	47.2	4	San Diego-Carlsbad-San Marcos, U.S.	283.3	7.3
5	San Diego-Carlsbad-San Marcos, U.S.	1519	10.5	5	Washington-Baltimore-N. Virginia, U.S.	269.0	6.9
41	Greater Toronto, ON	217	22.4	43	Metro Toronto, ON	30.0	12.9
57	Ottawa, ON	147	15.2	63	Montréal, QC	31.2	13.4
63	Montréal, QC	123	12.7	86	Greater Vancouver, BC	24.1	10.4
70	Greater Vancouver, BC	112	11.6	108	Ottawa, ON	19.0	8.2
113	Waterloo, ON	68	7.0	128	Saskatoon, SK	14.1	6.0

Data source: OECD (2013)

The table shows the five cities or regions that produce the largest number of patents worldwide, and the five cities that produce the most patents in Canada. For the ICT industries, patent creation tends to be highly concentrated in leading cities.

5.6 CONCLUSION

Several geographic areas of Canada exhibit strong IR&D activity. IR&D expenditures are concentrated in Ontario and Quebec for most manufacturing industries while British Columbia has a higher share of service sector IR&D. The citation measures for both patents and publications suggest that some of this manufacturing sector IR&D is high quality, such as communications equipment in Ontario and Quebec, and semiconductors in Ontario and British Columbia. In

the service sector, information and cultural industries appear strong in Quebec, and computer services in British Columbia and Ontario. Wholesale trade is strong in Alberta as is IR&D in the oil and gas extraction or petroleum and coal products industries.

The development of regional centres of IR&D in Canada in cities such as Waterloo and Ottawa indicate a strong clustering activity. The lack of data on clusters in Canada compared to Europe and the United States did not permit a more detailed analysis.⁵⁵ Nevertheless, the patent distribution data support the significant role of clusters in patterns of IR&D specialization across the country.

55 The European Commission supports the European Cluster Observatory (EC, 2013).

6

Canada's Industrial R&D Strengths

- **Defining IR&D Strength**
- **Identifying Canada's IR&D Strengths**
- **Regional Distribution of Canada's IR&D Strengths**
- **Conclusion**

6 Canada's Industrial R&D Strengths

Key Findings

- Based on the best available evidence, Canada's IR&D strengths are most concentrated in four industries: aerospace, ICT, oil and gas extraction, and pharmaceutical and medicine manufacturing. These industries demonstrate R&D strength by multiple measures, including those of magnitude and intensity, quality and impact, and trends.
- The regional distribution of R&D activity in these industries varies. Quebec accounts for the largest share of aerospace R&D in Canada, while Ontario has the greatest share of R&D activity in most ICT industries. R&D relating to the oil and gas industry is most probably concentrated in Alberta, British Columbia, and Atlantic Canada. Almost all pharmaceutical R&D is in British Columbia, Ontario, and Quebec.
- Conceptual and methodological data challenges argue for caution in identifying national IR&D strengths. Some of these challenges are unavoidable given the nature of IR&D. Assigning IR&D according to the product for which the IR&D is intended would allow for a more informative picture of Canada's IR&D landscape.

The main charge of the Panel was to document and describe the state of IR&D in Canada. In response, the preceding chapters have reviewed a broad range of available data on IR&D. The Panel was also asked to identify in which industries (or areas of technology) Canada shows IR&D strength relative to its peers. This chapter explores this aspect of the charge.

Identifying Canada's IR&D strengths is challenging conceptually, in terms of establishing by what characteristics a strength should be defined; and methodologically, in terms of finding reliable, internationally comparable data. The data challenges faced by the Panel (introduced in Section 1.4, and discussed in detail in Appendix B) made the identification and analysis of strengths difficult. The assignment of IR&D expenditures to the wholesale trade and scientific research and development services industries in Canada is particularly problematic. These two industries account for nearly 20 per cent of total IR&D in Canada, but this assignment does not allow inferences to be drawn on the type of IR&D effort undertaken with respect to the scientific work involved or its intended commercial applications. The patent and publication data relied on in this assessment only partially compensate. Despite these challenges, the Panel used the best available evidence to identify the areas of IR&D in which Canada most excels. Since the

concept of IR&D strength is inherently multifaceted and cannot be captured or summarized by any single measure, measures of magnitude and intensity, quality and impact, and trends were taken into consideration.

6.1 DEFINING IR&D STRENGTH

In defining the concept of IR&D “strength,” the Panel’s departure point was the definition of “science and technology strength” used by the first panel established by the Council on the State of Science and Technology in Canada (CCA, 2006), and later adopted by the recent Expert Panel on the State of Science and Technology (CCA, 2012a). The definition used by these panels includes work in the natural sciences, engineering, and mathematics, as well as in the humanities, social sciences, and arts. It highlights the complexity and multidimensionality of the concept of strength as applied to science and technology (S&T), or IR&D.

This Panel also considered the *ends* towards which IR&D efforts are targeted (i.e., sustainable growth and creation of new products or processes). Defined in this way, the concept of IR&D strength is a function of the degree to which IR&D efforts succeed at meeting this goal for a particular firm or industry. The resulting definition, which adapts the concept of S&T strengths to the IR&D context, is as follows:

As with science and technology strength, there is no simple, one-dimensional measure of Canada’s industrial R&D strengths. The concept is inherently multidimensional and encompasses i) the quality or impact of industrial R&D in Canada; ii) the magnitude or intensity of the Canadian effort in various sectors; iii) the trend of the foregoing factors (are we gaining or losing ground?); and iv) the extent to which R&D capabilities contribute to the sustainable growth of an industry through the creation of new products or process or the improvement of existing products or processes (Adapted from CCA, 2012a).

6.2 IDENTIFYING CANADA'S IR&D STRENGTHS

To identify areas of IR&D strength, the Panel focused on three types of measures: i) magnitude and intensity, ii) impact and quality, and iii) trends. Table 6.1 summarizes findings from these types of indicators for industries in Canada that accounted for more than one per cent of total IR&D expenditures in 2012.

These data paint a complex picture of Canadian IR&D strengths. Many industries excel by one or more of these measures. Measures related to intensity and magnitude highlight Canada's IR&D-intensive industries such as aerospace, communications equipment manufacturing, computer system design and services, and pharmaceuticals. They also show that oil and gas now accounts for over four per cent of all IR&D performed in Canada. The trend indicators include measures of general economic trends (GDP and export growth) as well as IR&D growth. Although IR&D expenditures have increased in many industries since 2000, important exceptions include communications equipment manufacturing, semiconductors, and pharmaceutical and medicine manufacturing. Likewise, many, though not all, industries have experienced growth in exports and GDP. Here performance is widely uneven, with rapid growth in the oil and gas industry, and declines in many manufacturing industries. Communications equipment and semiconductors were the exceptions, with neither demonstrating robust economic growth or expanding exports between 1997 and 2009.

Patent and publication citations were the two main indicators reviewed by the Panel of impact and quality, which related specifically to IR&D (rather than to innovation or economic success more broadly). These two measures capture separate, though related, dimensions of research impact: one based on scientific impact as manifested in academic journals, and the other related to impacts on other patents and inventions. Figure 6.1 plots these measures for all industries with sufficient publications and patents for the calculation of ARC scores (i.e., those industries with at least 30 patents or publications between 2003 and 2010).

Table 6.1

IR&D Indicators of Magnitude and Intensity, Impact, and Trends in Canada

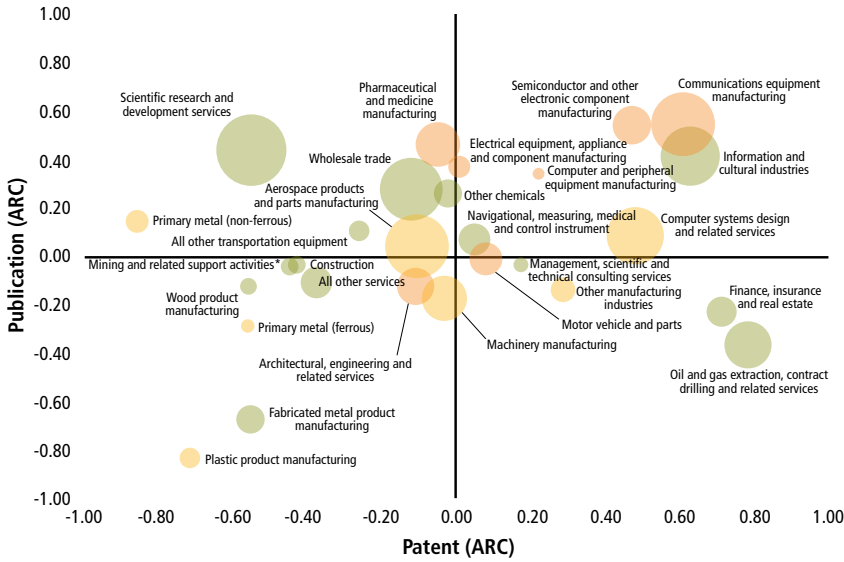
Industry	MAGNITUDE & INTENSITY				IMPACT		TRENDS		
	IR&D Share (2012) (>4%)	GDP Share (2012) (>1%)	IR&D Intensity (2012) (>3%)	Patent Share (2003–2010) (>3%)	Patent ARC (>1.0)	Pub. ARC (>1.0)	IR&D Growth (2001–2012) (>4%)	GDP Growth (1997–2008) (>5%)	Export Growth (1997–2008) (>5%)
Scientific research and development services*	11.17	0.34	32.78	3.39	0.54	1.60	15.42	7.71	6.42
Communications equipment manufacturing**	9.87	0.14	70.04	23.98	2.03	1.84	-4.75	-0.25	-0.85
Wholesale trade	8.40	5.39	1.55	3.32	0.88	1.33	5.37	4.97	5.24
Aerospace products and parts manufacturing	8.38	0.42	20.02	3.83	0.90	1.04	4.63	3.76	6.50
Computer systems design and related services*	8.23	1.17	7.02	4.88	1.69	1.08	4.76	7.71	6.42
Information and cultural industries	8.16	3.31	2.46	24.52	2.09	1.55	15.98	5.49	4.13
Oil and gas extraction, contract drilling and related services	4.17	5.79	0.72	0.45	2.86	0.68	15.53	14.60	15.38
Pharmaceutical and medicine manufacturing	4.15	0.30	13.80	3.34	0.95	1.65	-0.38	5.80	13.85
Machinery manufacturing	3.81	0.96	3.97	6.61	0.97	0.84	3.36	2.75	3.84
Semiconductor and other electronic component manufacturing**	3.09	0.10	31.00	2.05	1.67	1.83	-3.01	-0.25	-0.85
Navigational, measuring, medical and control instrument manufacturing**	2.42			4.88	1.05	1.07	0.66	-0.25	-0.85
Architectural, engineering and related services*	2.28	1.19	1.91	0.94	0.89	0.88	-0.81	7.71	6.42
Petroleum and coal product manufacturing	2.12	0.46	4.39	0.11		0.47	13.72	11.23	13.97
Motor vehicle and parts	2.05	1.02	1.98	3.50	1.08	0.99	-0.99	-2.76	-1.46

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Industry	MAGNITUDE & INTENSITY				IMPACT		TRENDS		
	IR&D Share (2012) (>4%)	GDP Share (2012) (>1%)	IR&D Intensity (2012) (>3%)	Patent Share (2003–2010) (>3%)	Patent ARC (>1.0)	Pub. ARC (>1.0)	IR&D Growth (2001–2012) (>4%)	GDP Growth (1997–2008) (>5%)	Export Growth (1997–2008) (>5%)
Other chemicals	1.83	0.49	1.13	2.95	0.98	1.30	3.15	-1.37	3.90
Finance, insurance and real estate	1.61	18.95	0.08	1.57	2.44	0.79	6.45	4.63	4.62
Other manufacturing industries	1.50			1.24	1.34	0.87	4.51	4.75	-1.39
Fabricated metal product manufacturing	1.39	0.87	1.61	0.82	0.54	0.44	7.86	4.02	3.08
Electrical power generation, transmission and distribution	1.17	1.97	0.05	0.00		0.60	-1.50	2.55	8.23
Electrical equipment, appliance and component manufacturing	1.08	0.26	0.34	4.65	1.00	1.5	-3.10	1.01	2.97
Primary metal (non-ferrous)	1.05	0.83	0.37	0.81	0.27	1.15	-0.47	3.72	6.88

Data source: Panel analysis based on Statistics Canada (2012a), and Science-Matrix calculations based on data from Scopus (Elsevier) and USPTO

The table shows summary indicators by industry for selected measures of magnitude and intensity, impact, and trends. Data are presented only for those industries that accounted for more than one per cent of total IR&D expenditures in 2012. Industries are listed in descending order by share of total IR&D. Shading indicates which industries satisfy the conditions stipulated under the variable headings across the second row from the top. IR&D expenditure and intensity data for the petroleum and coal product manufacturing industry is for 2010. IR&D intensity is expressed as a share of industry GDP. Patent share and patent average relative citation are based on patents filed at the USPTO between 2003 and 2010, as calculated by Science-Matrix. IR&D growth is the average annual growth rate in IR&D expenditures between 2001 and 2010. GDP growth and export growth are the compound annual growth rates between 1997 and 2008. *Data for GDP and export growth for architectural, engineering, and related services; computer system design and related services; and scientific research and development services are based on aggregated data from Statistics Canada for “professional, scientific, and technical services”. **Data for GDP and export growth for communication equipment manufacturing; navigational, measuring, medical and control instrument manufacturing; and semiconductor and other electronic component manufacturing are based on aggregated data from Statistics Canada for “electronic product manufacturing”.



*R&D Expenditure share for mining and related support activities is for 2011.

Data source: Statistics Canada (2012a); Science-Metrix tabulations based on data from Scopus (Elsevier) and the USPTO

Figure 6.1

Distribution of Patent and Publication Citations in Canada, 2003–2010

The figure shows an industry’s share of total IR&D (size of bubble), average relative citations of patents (x-axis), and average relative citations of publications (y-axis). Industry bubbles are also coloured according to whether IR&D expenditures have increased (green), decreased (red), or remained stable (yellow). Average relative citation scores are presented here as the hyperbolic tangent of the natural logarithm to produce a symmetrical scale, with zero equivalent to the world average.

The top-right quadrant of the figure corresponds to industries with both patent and publication citation levels above the world average. Nearly all of these industries are related to ICT:⁵⁶ communications equipment manufacturing, semiconductors, computer and peripheral manufacturing, electrical equipment

56 For the purposes of this analysis, and based on the NAICS aggregations used by Statistics Canada to report IR&D expenditures (e.g. Statistics Canada, 2012a), the Panel considers the following industries to be included in ICT: communications equipment manufacturing; computer and peripheral manufacturing; semiconductor and other equipment manufacturing; navigational, measuring medical and control instrument manufacturing; other computer and electronic products, electrical equipment, appliance and component manufacturing; information and cultural industries; and computer system design and related services. This definition is broadly consistent with Statistics Canada’s official statistical definition of the ICT sector, though that used by Statistics Canada provides greater detail in certain industries. Some of the data relied on by the Panel, however, were not available at finer levels of granularity. The full set of NAICS codes included in Statistics Canada’s definition of the ICT sector are 3333, 33411, 33421, 33422, 33431, 33441, 33451, 33592, 4173, 41791, 5112, 517 to 518, 51913, 53242, 5415, and 8112.

manufacturing, and instrument manufacturing. The two service industries that appear are also ICT based: information and cultural industries, which include Canada's telecommunications companies; and computer system design and related services. This pattern is suggestive of a broadly dispersed Canadian strength in many areas of IR&D related to ICT and related electronic technologies that may be involved in instrument manufacturing or other electronic products. That said, IR&D expenditures have declined in recent years in several of these industries, particularly those in manufacturing.

Turning to the bottom-right quadrant, Canadian patents appear to have a high level of impact in oil and gas, and in finance, insurance, and real estate. Patent citations are nearly three times the world average for patents associated with oil and gas, indicating that technologies (or at least intellectual property) developed by Canadian oil and gas firms have a high level of impact. While publication citations in both of these industries are below the world average, this may be more reflective of the nature of the IR&D undertaken, which could be less amenable to publication in scientific journals, than of any weakness in the IR&D activities. The oil and gas and the finance, insurance, and real estate industries account for relatively small shares of all Canadian industry publications (1.9 per cent and 0.8 per cent, respectively).

A closer, firm-level examination of the data reveals important distinctions. For patents in finance, insurance, and real estate, a single firm engaged in the management and licensing of telecommunications and semiconductor patents (classified by NAICS as a "lessor of non-financial intangible assets") is responsible for the high level of patent citations. Patent citations for this industry therefore do not actually reflect either a strong IR&D base or IR&D performed in response to industry-specific needs and opportunities. Patent data for the oil and gas industry reveal that Canada's relatively high level of patent citations is driven by a relatively small number of patent-holding firms providing oil and gas drilling or well-servicing technologies, rather than by larger, well-known Canadian energy corporations.

The top-left quadrant contains industries with high scientific impact according to journal article citations, but less impact according to patents. Pharmaceutical and medicine manufacturing is the most notable industry here, with citation levels roughly 60 per cent above the world average. Although Canadian scientists working in this industry have a relatively high level of scientific impact, little of it appears to be captured in intellectual property. Scientific research and development services and wholesale trade also appear in this quadrant. As discussed previously, it is difficult to interpret the implications of data in these industries. As a result,

the Panel did not focus on these results in detail, except to note that they most likely reflect IR&D activities in support of many different industry types and commercial applications.

Finally, the bottom-left quadrant represents areas of IR&D in which Canada's research impact is below the world average. A variety of industries appear here, most notably plastic product manufacturing and fabricated metal manufacturing.

6.2.1 Four Industries of IR&D Strength

Taken together, Figure 6.1 and Table 6.1 provide a useful composite picture of Canada's IR&D strengths. These results speak to the breadth and complexity of IR&D activity in Canada, and reaffirm the Panel's baseline assumption that the concept of IR&D strength is inherently multifaceted and cannot be captured or summarized by any single measure. Together, however, the indicators reviewed above led the Panel to identify the following as key industries of IR&D strength in Canada:^{57,58}

- **Aerospace products and parts manufacturing:** The aerospace industry shows strength by six of the nine measures in Table 6.1, including in all three categories (magnitude/intensity, quality/impact, and trends). In addition, as noted in Chapter 4, Canada's aerospace industry accounts for a comparatively large share of world exports. There are also some causes for concern. On measures of research impact, the aerospace industry's levels of patent and publication citations are only average by world standards. While IR&D expenditures and exports have significantly grown in recent years, overall economic output as reflected in GDP growth is less robust. Nevertheless, on balance, the available evidence suggests aerospace is an important area of IR&D activity in Canada.
- **Information and communication technologies:** Many industries associated with ICT show signs of strength in Canada, including communications equipment manufacturing, computer systems design and related services, and information

57 Note that while both wholesale trade and scientific research and development services also show strength across many measures in Table 6.1, these industries are *not* discussed here for the reasons outlined at the beginning of the chapter, namely that R&D activities in these industries apply to many different areas of research, technology platforms, and industrial and commercial applications.

58 Clearly, the industries discussed in this section, as with many other industries in Canada, have benefitted from government support of various kinds over the past decades, including tax, regulatory, and trade measures. It is beyond the mandate of this Panel to consider to what degree R&D strength in these industries is directly attributable to past federal or provincial government action. IR&D should not be viewed as having arisen in isolation from the effects of previous industrial support policies. For a recent review of federal programs supporting IR&D in Canada, see Industry Canada (2011a).

and cultural industries. All of these excel by five or more of the measures listed in Table 6.1, and computer system design and related services is the only industry that shows strength across all nine indicators. As noted above, these industries also stand out with both patent and publication citation rates above the world average. They also account for a large share of Canada's IR&D activity, and, in some cases, have had strong records of growth. The two service industries featured here (computer system design and information and cultural services) have had robust growth. The recent assessment of the State of Science and Technology in Canada (CCA, 2012a) also identified ICT as an area of academic strength for Canadian researchers. Of more concern, however, are the declining IR&D spending and relatively low levels of economic growth in recent years in electronic product manufacturing industries such as communications equipment and semiconductors. Should such trends continue, it is questionable whether these industries will remain areas of strength in the future.

- **Oil and gas extraction:** Oil and gas is traditionally an industry of low IR&D intensity. Nevertheless, in Canada the industry has grown rapidly over the past decade, accompanied by a parallel expansion in IR&D investment. IR&D expenditures grew at an average annual rate of over 15 per cent between 2001 and 2012, and oil and gas is now one of only eight industries that account for more than four per cent of Canada's total IR&D expenditures. Citations reveal that patents held by Canadian oil and gas firms are of high impact, particularly those associated with firms engaged in drilling technologies and well services, and Canadian IR&D accomplishments in extraction of non-traditional oil and gas are widely recognized (CCA, 2012a). Overall, oil and gas shows strength by six of the nine measures included in Table 6.1. In addition, survey data reviewed in Chapter 4 found that Canadian contributions related to energy generation technologies are highly regarded internationally.
- **Pharmaceutical and medicine manufacturing:** Canada excels by six of the nine measures included in Table 6.1. The industry accounts for a large share of IR&D spending in Canada. That share may also be understated given that some pharmaceutical firms may be captured in wholesale trade. Data from scientific publications also suggest that researchers working in Canadian pharmaceutical firms are highly cited, which correlates with the Council's findings about Canada's generalized research strength in the field of Clinical Medicine (CCA, 2012a). And, while Canada's patent citation levels are only average, Canadian firms account for a significant portion of patent filings at the United States Patent and Trademark Office (USPTO) related to new drugs and pharmaceuticals. As discussed in Chapter 3, by patents filed at the USPTO, Canada ranked fourth in the world in biotechnology, seventh in medical technology and sixth in pharmaceuticals. Pharmaceutical manufacturing is

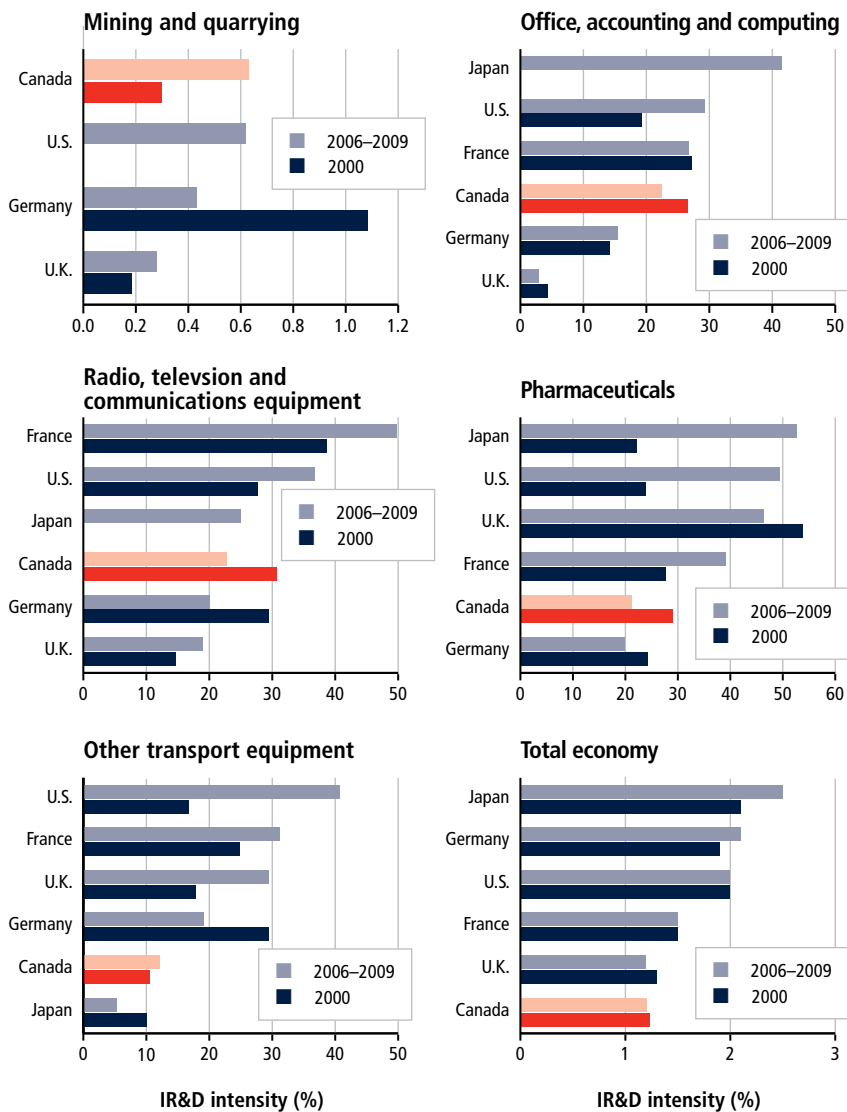
also one of the few IR&D-intensive manufacturing industries in Canada that maintained its export performance. On the other hand, the strength of the industry is also a cause for concern because IR&D expenditures by Canadian firms fell by nearly 31 per cent in 2008, and have since remained at that lower level (Statistics Canada, 2012b).⁵⁹ Globally, IR&D expenditures fell by three per cent in 2010 after decades of steady growth (CMR International, 2011).

International comparisons of IR&D intensities reinforce the competitiveness of these Canadian industries in IR&D. Because these strengths are distributed across the Canadian economy, the Panel decided that the best comparison group was that of large industrial economies that might have diversified strength across industries, recognizing that some European economies might have very high IR&D intensities in one particular industry. Figure 6.2 shows the IR&D intensities of those industries judged to show IR&D strength in Canada according to the international data available, and of Canada's business sector as a whole.

The cross-country comparisons suggest that IR&D intensities in those Canadian industries displaying strong IR&D are within range of these large economies. IR&D intensity is particularly high in the mining and oil and gas sector. Unfortunately, no precise international classification concordance exists, particularly when comparing IR&D expenditures of some service industries (such as scientific research and development services). International data that accord with the Panel's approach to ICT are available for office, accounting, and computing equipment, and radio, television, and communications equipment, and suggest that the IR&D intensity of these industries in Canada is relatively strong. Data on the aerospace industry are only available within the more diversified "other transport equipment" industry. Again, IR&D intensity in this Canadian industry is comparable, bearing in mind the following: other countries may have substantial IR&D expenditures related to railroads, global manufacturers such as Airbus and Boeing are located in these countries, and substantial defence expenditures may also be appearing in the industry.

Nevertheless, the final chart in Figure 6.2 shows that Canada's overall IR&D intensity is the lowest among this comparator group, which is reconciled by the relative small share held by these IR&D-intensive industries in Canada's economy, with the exception of the mining and oil and gas and other transport equipment industries.

59 Pharmaceutical R&D facilities have been closed by companies such as Astra Zeneca, Johnson & Johnson, and Merck (Canadian Press, 2012).



No 2000 data for mining and quarrying in France (and 2006–2009); radio, TV and communications equipment and office, accounting and computing in Japan; and mining and quarrying in the United States. Japan's mining and quarrying sector was excluded because of its small scale. Mining and quarrying includes oil and gas extraction. Other transport equipment includes aircraft and spacecraft.

Data source: Panel analysis based on OECD (2011b, 2013)

Figure 6.2

IR&D Intensities of Industries Showing IR&D Strength in Canada and Total Economy, Selected Economies

The figure shows the IR&D intensities of industries displaying IR&D strength in Canada. IR&D strength in many of these industries is comparable to that of large economies. However, the smaller relative size of these industries drags down Canada's overall IR&D intensity.

6.3 REGIONAL DISTRIBUTION OF CANADA'S IR&D STRENGTHS

As discussed in Chapter 5, the large majority of Canada's IR&D occurs in Ontario and Quebec. Although the pattern of distribution is similar for the four industries of IR&D strength identified above, there are notable variations across industries. Quebec and Ontario account for around three-quarters of the IR&D associated with the four industries (see Table 6.2):

- **Aerospace products and parts manufacturing:** Nearly three-quarters of IR&D in the aerospace industry takes place in Quebec, with firms such as Bombardier, CAE, Pratt & Whitney, and Bell Helicopter all having operations in the Montréal region.
- **Information and communication technologies:** The distribution of IR&D expenditures across the ICT industries identified in Table 6.1 is more mixed; however, Ontario accounts for the largest share of IR&D activity in most of these industries. For example, IR&D related to communications equipment manufacturing is highly concentrated in Ontario, which accounts for 88 per cent of the total. Similarly, Ontario accounts for the greatest share of IR&D undertaken in the semiconductor, instrument, electrical equipment and appliance, information and cultural industries (which includes telecommunications), and computer system design and related services. In general, Quebec accounts for approximately one-quarter of IR&D expenditures in many of these industries (particularly ICT services), and British Columbia accounts for between 10 per cent and 15 per cent.
- **Oil and gas extraction:** The data do not allow for a regional breakdown in this industry,⁶⁰ with only British Columbia registering IR&D spending. But, if IR&D is broadly co-located with major oil and gas activity, a substantial amount of IR&D activity in this industry is likely occurring in Alberta and Atlantic Canada; as noted in Chapter 5, Alberta accounts for the majority of Canadian patents related to oil and gas.
- **Pharmaceutical and medicine manufacturing:** Almost 90 per cent of IR&D expenditures in pharmaceutical manufacturing are concentrated in Ontario and Quebec, with much of the rest in British Columbia.

60 In some cases, Statistics Canada suppresses data on IR&D expenditures to protect the identities of individual firms. As a result, the sum of IR&D expenditures based on a provincial or regional breakdown may not be the same as the total for the country as a whole.

Table 6.2
Provincial Distribution of BERD by Industry, 2010

Sector	Atlantic Canada	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia	Share of Total Industry BERD Accounted for
	%							
Total BERD (All Industries)	1.8	31.0	45.0	1.4	1.0	9.1	10.7	100
Oil and gas extraction	–	–	–	–	–	–	44.5	45*
Aerospace products and parts manufacturing	0.2	75.8	22.9	0.9	0	0.2	–	100
Pharmaceutical manufacturing	1.3	39.3	49.5	–	0.1	–	4.9	95
Information and communication technologies								
Communications equipment manufacturing	–	7.4	88.0	–	–	0	2.3	98
Computer systems design and related services	2.2	30.7	44.9	1.0	0.5	5.8	14.9	100
Electrical equipment, appliance and component manufacturing	–	21.4	50.6	–	0.6	1.3	24.7	99
Information and cultural industries	2.4	25.2	49.6	–	–	6.9	11.1	95
Navigational, measuring, medical and control instrument manufacturing	1.9	23.8	62.5	–	–	3.7	7.6	99
Semiconductor and other electronic component manufacturing	–	14.5	65.1	–	–	4.4	15.2	99
Total (Industries of IR&D Strength)	1.0	29.5	46.2	0.3	0.1	2.7	12.2	93

Data source: Statistics Canada (2012a)

The table reports the percentage of BERD by region/province for 2010. Note that data are suppressed by Statistics Canada to protect the identity of survey respondents in some cases, and where data quality is a concern. (–) indicates no data available. The final column shows the percentage of total industry BERD accounted for by this regional breakdown. *Data are suppressed for oil and gas, where regional/provincial totals account for only 45 per cent of total Canadian IR&D in that industry. Only those ICT industries included in Table 6.1 (i.e., those that account for at least one per cent of total IR&D in Canada) are shown here. Totals may not add up due to rounding.

Only 1.4 per cent of the total IR&D in Canada associated with these industries of IR&D strength occurs in Atlantic Canada, Manitoba, or Saskatchewan. Low levels of IR&D activity associated with information and cultural industries, and computer system design, occur in the Atlantic Provinces; and with aerospace and computer system design in Manitoba. None of these industries, however, show a significant IR&D presence in Saskatchewan.

This distribution is also consistent across other indicators of IR&D activity such as patents or publications. As shown in Chapter 5, Ontario and Quebec account for the largest shares of IR&D performed in these industries though British Columbia shows strength by several measures in semiconductors. Patent citations in oil and gas are also high in Alberta, again suggesting that much of Canada's high-impact oil and gas IR&D stems from that province.

Other provinces may show IR&D strengths in other industries. For example, earlier analysis suggested that IR&D in the Atlantic Provinces is strong by several measures in food manufacturing (Table 5.4). The distribution of IR&D expenditures in the four industries of IR&D strength closely mirrors the overall distribution of IR&D spending across provinces in all industries (see Table 6.2). On the whole, Canada's IR&D activities in the industries of IR&D strength are most heavily concentrated in Ontario and Quebec, and then British Columbia and Alberta to a lesser degree.

6.4 CONCLUSION

This chapter has identified four industries in which Canada shows IR&D strength by multiple measures: aerospace, ICT, oil and gas extraction, and pharmaceuticals. There are no doubt many other niche areas of research and technological development in which Canadian researchers (both in industry and academia) are making high-impact contributions and achieving high levels of excellence and commercial success. Nothing precludes Canadian researchers and businesses from making advances and contributions across all industries. A unique aspect of new technologies is that even one small firm can have a large impact on a globally dispersed industry by introducing the right technology at the right time. Canada's pattern of IR&D strengths is also inherently dynamic; at any given time, new research and technological strengths may be emerging and previous areas of strengths may be declining.

An analysis such as the one offered in this chapter should be regarded as a snapshot in time of a dynamic, constantly evolving system. Nevertheless, the concentration (or dispersion) of IR&D resources across industries matters, both at a national level and on an industry-by-industry basis. In the Panel's view, the balance of evidence suggests that Canadian IR&D strengths and successes are most highly concentrated in the four industries identified above.

The next chapter further reflects on these areas of IR&D strength by considering the extent to which they are aligned with Canada's S&T strengths as well as industry needs and Canada's economic strengths.

7

Knowledge Production and Barriers to Translation

- **The Alignment of S&T, IR&D,
and Economic Strengths**
- **The Production of Knowledge:
A Tale of Two Incentive Structures**
- **Canadian S&T and Innovation Policy**
- **Canadian Barriers to Knowledge Translation**
- **Conclusion**

7 Knowledge Production and Barriers to Translation

Key Findings

- In general, although there is limited alignment between areas of S&T, IR&D, and economic strength, the Panel identified four areas of some congruence: clinical medicine S&T and pharmaceutical IR&D, information and communication technologies S&T and IR&D, oil and gas IR&D and economic performance, and aerospace IR&D and economic performance.
- This limited alignment may be the result of different incentives in the production of public and private knowledge. The priority-based incentive structure in the public sector often generates knowledge without immediate market potential.
- S&T performed in the private sector is typically aligned with IR&D, as private-sector resources are primarily invested in market-driven research and development activities. Conversely, S&T performed in the public sector is primarily driven by scientific curiosity, resulting in lack of alignment between public-sector S&T efforts and the needs of IR&D.
- Canada performs a similar amount of public R&D, but significantly less IR&D than comparator countries. To receive the full benefits of public R&D, public policies in Canada need to encourage IR&D, but without redistributing resources away from public R&D.
- Since the public and private sectors respond to different incentives and produce different types of knowledge, they require different types of policies: S&T policy for the public sector and innovation policy for the private sector.
- Increased competition increases demand for innovation, and, in turn, IR&D. Five Canada-specific barriers to the translation of S&T knowledge into innovation and wealth creation advanced by the academic and public policy literature are: technology transfer, managerial expertise, business support, public procurement, and business culture.

S&T is the foundation of both a strong economy and a progressive society. S&T knowledge provides “the ideas from which novel products originate, the tacit comprehensions that enable incremental innovation, the insights to spot market opportunities and devise solutions to diverse problems, and the abilities to design efficient and equitable public policies” (CCA, 2013). As illustrated in CCA (2012a), the state of Canadian S&T has been excellent, ranking among the leaders across a set of comparator countries. In this sense, Canada’s fundamental S&T knowledge base is very solid.

As the previous chapters have indicated, on the whole Canada's performance in IR&D has been less than stellar, whether measured by inputs (Chapter 2) or outputs (Chapter 3). While there are certainly pockets of industry-level (Chapter 6) and provincial strength (Chapter 5), a disconnect exists between Canada's strong S&T base and relatively weak IR&D performance. Moreover, as discussed in Chapter 4 and elsewhere (CCA, 2009; Industry Canada, 2011a; Miller & Côté, 2012; OECD, 2012a), the productivity of the Canadian business sector is sub-par.

Nonetheless, as discussed in Chapter 1, the performance of Canadian firms and the Canadian economy as a whole has been strong relative to most OECD peers (OECD, 2012a). The Panel noted that Canada's strong economic performance through the global economic crises of the last decade may have led to a perception that all aspects of its performance must be strong. Instead, the data suggest that Canada weathered the global economic downturn *despite* its relatively poor IR&D performance. Canada's economic stability and growth during this period can be attributed to a number of other factors independent of IR&D performance, including a well-educated workforce and increasing global market prices for Canada's natural resource products (CCA, 2009; OECD, 2012a). These factors have been buttressed by effective financial regulation, openness to skills and ideas from abroad, and low and stable inflation. The Panel voiced concern over the potential risk to the Canadian economy associated with relying on rising prices of non-renewable resources that may not be sustainable in the light of changing patterns of global demand beyond Canada's control. Given the global trend towards knowledge-based economies, Canada's poor IR&D performance represents a risk to long-term economic performance.

This concomitance of strong S&T, relatively low levels of IR&D, low productivity growth, and strong economic performance appears, at first blush, to be something of a paradox. This apparent paradox, however, is simply an artefact of the classical linear ("science-push") model of the relationships between S&T, IR&D, innovation, and economic performance (Bush, 1945). Although this linear thinking pervades much of the public policy in this space, it is well established that these relationships are *complex*, influenced by a wide range of factors and subject to spillovers; *dynamic*, dependent on and changing with time; and *non-linear*, characterized by feedback loops between S&T, IR&D, innovation, and economic performance (CCA, 2013). It is not simply a process of taking an idea from a scientific article in a research journal, solving a few engineering problems, and rushing it through to production. IR&D is fraught with risk and driven by entrepreneurial spirit. It responds to market needs, such as a new process to extract natural gas that will result in lower costs; or it creates completely new markets in social media and communications. A firm in a vibrant industry will search for

new ideas in any location, including academe. Often industry needs to build on the scientific knowledge generated by universities or explore neglected areas to make the scientific breakthroughs itself because some problems are ignored by academics. And the process can work in reverse. Technological breakthroughs in measurement and testing by equipment developed in industry have been critical to allowing science to advance in the field of genomics. IR&D has therefore led to scientific advances in university labs. These feedback effects are highly complex in practice, which makes translating science into IR&D a dynamic and non-linear process. It follows that disentangling these relationships is challenging both conceptually and practically. In this sense, it would not be surprising, let alone paradoxical, if no direct correspondence existed between S&T, IR&D, and economic performance.

This chapter first explores the degree to which there are, in fact, direct congruences between S&T, IR&D, and economic strengths in Canada. It goes on to identify areas of Canadian economic strengths and attempts to match these with the S&T strengths identified in the CCA (2012a) report on the state of S&T in Canada and the IR&D strengths identified in Chapter 6. In doing so, this section directly answers Sub-question 2:

In which scientific disciplines and technological applications are our relative strengths most aligned with Canada's economic strengths/industry needs?

With this in mind, the remainder of the chapter focuses on knowledge production incentives and knowledge translation to address Sub-question 3:

What are the key barriers and knowledge gaps in translating Canadian strengths in S&T into innovation and wealth creation?

Specifically, it contrasts the incentives that underpin the production of university-led S&T with those that drive the production of knowledge in industry. The principal finding is that these incentives lead to the production of different types of knowledge, with university-led S&T knowledge often not easily translated into knowledge relevant for firm innovation. Noting that some ideas do in fact make it to market and that other countries appear to better leverage their S&T knowledge base, the chapter next considers two dimensions of the Canadian landscape. First, the Canadian approach to S&T and innovation public policy is contrasted with that of other countries. Second, five barriers highlighted in the Canadian debate that might inhibit or prevent the translation of S&T knowledge into innovation and ultimately wealth creation are discussed.

7.1 THE ALIGNMENT OF S&T, IR&D, AND ECONOMIC STRENGTHS

As mentioned, part of the Panel's mandate was to consider the degree of alignment between Canada's IR&D strengths and both industry needs and economic strengths. These are two distinct tasks.

Addressing whether Canadian IR&D strengths are meeting industry needs is problematic from three standpoints. First, industry needs are diverse, varying according to the nature of technologies relevant to, and market conditions faced by, a given industry. For instance, differences in the product-development process mean that the needs potentially filled by IR&D in the pharmaceutical industry may bear little resemblance to the needs potentially filled by IR&D in automotive industry. Second, multiple types of needs of a particular industry can range from needs related to development and commercialization of new products to needs related to internal process and organizational methods. Third, some needs are relatively common across industries such as improving energy efficiency, reducing environmental impacts, or adopting productivity-enhancing ICT solutions.

Considering whether these types of needs are aligned with Canada's IR&D strengths, however, shifts the focus away from the analysis of IR&D activities towards analysis of domestic market conditions. Given these challenges, the Panel struggled with how to best consider whether areas of IR&D strength were aligned with industry needs. Eventually, it decided there was no practical way, given the data available, to effectively answer this question in the required depth. Whether IR&D efforts are meeting Canadian industrial needs in a particular industry is a matter for detailed industry studies or technology road mapping exercises.

At the firm level, it is reasonable to assume that IR&D activities are undertaken to meet the needs of the performing firm, whether developing products, design processes, or organizational structures, or responding to external regulations. It follows that in industries where Canada shows signs of IR&D strength, IR&D activity is, by and large, meeting those industries' needs and productively contributing to its commercial successes. By corollary, in industries that are not areas of IR&D strength, it stands to reason that IR&D is not an integral part of business strategy (CCA, 2009). Industry needs here are met by a host of other business strategies that are not IR&D related. In simple terms, firms spend on their needs; if a firm is not spending on IR&D, then it does not consider IR&D a need. Sections 7.3 and 7.4 discuss in more detail why this may be the case for a greater number of firms in Canada than elsewhere.

The challenge of identifying economic strengths is also complex as there is no internationally accepted definition or corresponding theoretical concept from which a definition could be logically derived. As such, a particular industry could be deemed “strong” according to a host of indicators, including GDP, GDP share, employment, exports, etc. Ultimately, an indicator of economic strength comes with its own unique set of benefits and drawbacks (CCA, 2013). As such, the Panel chose to consider three robust and conceptually appealing indicators of economic strength at the industry level: growth, share of Canadian economy, and share of Canadian economy relative to the OECD. First, the growth rate of an industry (GDP growth) is a *dynamic* indicator of the importance of that industry to the economy. Second, the share of an industry to total Canadian GDP provides a measure of the size of a given industry relative to the rest of the Canadian economy. This can act as a proxy for the *absolute* strength or importance of an industry in Canada. Third, the ratio of industrial shares provides a measure of how large a Canadian industry is compared to the OECD average. This can act as a proxy for the *relative* strength or importance of an industry in Canada.

Five of the 39 industries that make up the Canadian economy accounted for over 40 per cent of GDP, on average, for the period 1997 to 2008: finance, insurance, and real estate (18.7 per cent); construction (5.7 per cent); retail trade (5.4 per cent); oil and gas extraction and contract drilling and related services (5.3 per cent); and wholesale trade (5.3 per cent).⁶¹ Table 7.1 lists 2008 GDP contributions, 2008 share of the economy, nominal GDP growth from 1997 to 2008, and average share of the economy from 1997 to 2008 for all industries in the Canadian economy. Of the 39 industries, only a handful account for larger shares in 2008 than their average share over the preceding 11 years. Three of these are particularly notable: oil and gas extraction and contract drilling and related services, mining and related support activities, and construction. These three industries have grown significantly over the last decade and currently represent much larger shares of the economy than their historical average.

61 The industry classification “All other services” combines a wide and somewhat disparate set of service industries that are not easily separated. This classification was excluded from the analysis.

Table 7.1
GDP by Industry in Canada, 1997–2008

Industry classification	2008		1997–2008	
	GDP (\$ millions)	GDP Share (%)	Average Share of GDP (%)	GDP Growth (%)
Agriculture	21,245	1.41	1.38	4.34
Forestry, logging and support activities for forestry	5,780	0.38	0.60	-0.61
Fishing, hunting, trapping and animal aquaculture	900	0.06	0.09	0.50
Oil and gas extraction, contract drilling and related services	129,510	8.58	5.34	14.60
Mining and related support activities	25,245	1.67	1.12	9.28
Electric power generation, transmission and distribution	30,331	2.01	2.27	2.55
Other utilities	4,122	0.27	0.31	2.61
Construction	107,603	7.13	5.73	7.95
Food manufacturing	22,049	1.46	1.60	3.94
Beverage and tobacco product manufacturing	6,101	0.40	0.54	1.81
Textiles	3,466	0.23	0.55	-4.32
Wood product manufacturing	7,996	0.53	1.01	-1.16
Paper manufacturing	9,341	0.62	1.05	-1.23
Printing and related support activities	5,942	0.39	0.51	2.68
Petroleum and coal product manufacturing	5,938	0.39	0.33	11.23
Pharmaceutical and medicine manufacturing	4,082	0.27	0.31	5.80
Other chemicals	9,123	0.60	0.94	-1.37
Plastic product manufacturing	7,446	0.49	0.65	3.54
Rubber product manufacturing	1,083	0.07	0.18	-5.60
Non-metallic mineral product manufacturing	6,361	0.42	0.47	4.42

continued on next page

Industry classification	2008		1997–2008	
	GDP (\$ millions)	GDP Share (%)	Average Share of GDP (%)	GDP Growth (%)
Primary metal (ferrous and non-ferrous)	14,865	0.98	1.07	3.72
Fabricated metal product manufacturing	14,964	0.99	1.20	4.02
Machinery manufacturing	13,614	0.90	1.10	2.75
Computer and peripheral equipment manufacturing	716	0.05	0.08	-2.18
Electronic product manufacturing	6,502	0.43	0.64	-0.25
Electrical equipment, appliance and component manufacturing	3,755	0.25	0.34	1.01
Motor vehicle and parts	11,100	0.74	1.82	-2.76
Aerospace products and parts manufacturing	7,427	0.49	0.52	3.76
All other transportation equipment	1,787	0.12	0.19	-0.39
Furniture and related product manufacturing	5,512	0.37	0.49	3.94
Other manufacturing industries	4,451	0.29	0.33	4.75
Wholesale trade	78,153	5.18	5.29	4.97
Retail trade	83,436	5.53	5.42	5.84
Transportation and warehousing	62,486	4.14	4.42	4.20
Information and cultural industries	49,537	3.28	3.33	5.49
Finance, insurance and real estate	274,133	18.16	18.65	4.63
Professional, scientific and technical services	68,925	4.57	4.17	7.71
Health care and social assistance	38,422	2.55	2.50	5.50
All other services	355,752	23.57	23.44	5.16

Data source: Statistics Canada (2013a) and Panel calculations

The table provides GDP by industry in both nominal dollars and as a share of total GDP in 2008. It also provides average GDP share and GDP growth over 1997–2008, with GDP growth calculated as compound annual growth. The grey rows are industries that accounted for greater than five per cent of average GDP and/or compound annual growth of more than eight per cent.

Table 7.2
Industry Shares, Canada and Average OECD, 2000–2006

OECD industry classification	2006				2000–2006	
	Average OECD share of industry GDP (%)	Canada's share of industry GDP (%)	Relative size in Canada to OECD (%)	Canada's rank	Average OECD share growth (%)	Canada's share growth (%)
Agriculture, hunting, forestry, fishing	2.61	1.64	63	22	-5.3	-0.1
Mining and quarrying	2.60	8.61	331	2	2.9	3.1
Food products, beverages and tobacco	2.30	1.95	84	20	-2.3	0.8
Textiles, textile products, leather and footwear	0.79	0.36	46	23	-5.8	-5.6
Wood and products of wood and cork	0.53	0.82	154	8	-1.8	-4.6
Pulp, paper, paper products, printing and publishing	1.46	2.32	159	3	-4.7	0.6
Coke, refined petroleum products and nuclear fuel	0.51	0.35	68	14	1.9	3.1
Chemicals excluding pharmaceuticals	1.12	0.69	61	21	9.5	8.0
Pharmaceuticals	0.70	0.38	54	19	-11.2	-4.9
Rubber and plastics products	0.75	0.72	96	16	-1.1	-2.8
Other non-metallic mineral products	0.88	0.47	54	27	-1.3	1.7
Basic metals and fabricated metal products	2.50	2.22	89	19	0.3	-2.6
Machinery and equipment	1.58	1.05	66	21	-0.3	-3.2
Office, accounting and computing machinery	0.13	0.06	43	17	-11.6	0.4

continued on next page

OECD industry classification	2006				2000–2006	
	Average OECD share of industry GDP (%)	Canada's share of industry GDP (%)	Relative size in Canada to OECD (%)	Canada's rank	Average OECD share growth (%)	Canada's share growth (%)
Electrical machinery and apparatus	0.74	0.23	31	28	-1.4	-7.1
Radio, television and communications equipment	0.88	0.47	53	18	-3.7	-9.0
Medical, precision and optical instruments*	0.59	–	–	–	-0.1	–
Motor vehicles, trailers and semi-trailers	1.14	1.18	104	13	0.1	-11.7
Aircraft and spacecraft	0.17	0.44	266	3	-3.0	-2.8
Manufacturing and recycling	0.66	0.77	116	12	-2.5	-0.2
Electricity gas and, water supply	2.53	2.46	97	14	1.5	-3.4
Construction	6.55	6.47	99	14	1.5	3.0
Wholesale and retail trade — restaurants and hotels	14.66	14.08	96	20	-0.1	1.0
Transport, storage and communications	7.69	6.92	90	23	-0.7	1.0
Finance, insurance, real estate and business services	25.58	25.43	99	16	1.1	-0.7
Community, social and personal services	20.64	19.78	96	21	0.6	-0.2

* Canadian data are not collected for this industry.

Data source: OECD (2011b) and Panel calculations

The table provides the average OECD and Canadian GDP shares by industry in 2006, the ratio of these shares, and Canada's rank relative to the OECD average. It also provides the annual growth of the OECD average and Canadian GDP shares over the 2000-2006 period. The OECD average is an average across OECD countries for which industry data exist. They grey rows are industries greater than 1.25 times the OECD average share.

Since OECD data are based on the ISIC rather than the NAICS codes, direct comparison across each industry is not possible. Nonetheless, these data portray a similar picture of absolute Canadian economic strengths. In terms of relative economic strength (i.e., the ratio of Canadian to OECD industry size), these data suggest six such industries: wood and products of wood and cork; pulp, paper, paper products, printing, and publishing; motor vehicles, trailers, and semi-trailers; aircraft and spacecraft; and manufacturing and recycling. These six industries have proportionately larger shares of the Canadian economy than that of their OECD comparators. Table 7.2 lists industry share in the average OECD economy, industry share in the Canadian economy, industry size in the Canadian economy relative to the OECD average, and Canadian industry rank by size against other OECD countries.

Four industries in Canada rank as significantly large within the OECD (i.e., at least 1.25 times the OECD average). First, the share of the mining and quarrying industry, which includes oil and gas extraction, in the Canadian economy is roughly 330 per cent the size of the OECD average and is the second largest out of 30 OECD countries. Second, the share of the aircraft and spacecraft industry in the Canadian economy is roughly 270 per cent the size of the OECD average and is the third largest out of 24 OECD countries. Third, the share of the pulp, paper, paper products, printing, and publishing industry in the Canadian economy is roughly 160 per cent the size of the OECD average and is the third largest out of 33 OECD countries. Fourth, the share of wood and products of wood and cork in the Canadian economy is roughly 155 per cent the size of the OECD average and is the eight largest out of 33 OECD countries.

Taken together, Tables 7.1 and 7.2 provide some perspective on which industries can be considered areas of Canadian economic strength. Taking those industries that accounted for greater than five per cent of average GDP and/or compound annual growth of more than eight per cent over 1997–2008,⁶² and those industries greater than 1.25 times the OECD average share, the Panel identified six broad industries that play an integral role in the economy: aerospace;⁶³ oil, gas, and mining;⁶⁴ construction; forestry;⁶⁵ financial, insurance, and real estate; and

62 The cut-off of eight per cent is used because it represents relatively rapid growth of industry in Canada: 1.5 times the average growth rate (5.25 per cent) of the economy over the 1997–2008 period.

63 This includes aircraft and spacecraft.

64 This includes oil and gas extraction, contract drilling, and related services; petroleum and coal product manufacturing; and mining and related support activities.

65 This includes pulp, paper, paper products, printing and publishing; and wood and products of wood and cork.

retail and wholesale trade. When matched against the six areas of S&T strength identified in the Council of Canadian Academies (CCA, 2012a) report on S&T in Canada and the four areas of IR&D strength identified in Chapter 6, there appear to be four broad areas of alignment (see Figure 7.1): clinical medicine S&T and pharmaceutical IR&D, information and communication technologies S&T and IR&D, oil and gas IR&D and economic performance, and aerospace IR&D and economic performance.

Canada's research strength related to clinical medicine is likely to contribute to the strength of the pharmaceutical and medicine manufacturing industry. Likewise, Canada's research strength in ICT also helps IR&D relating to these technologies. Canada's IR&D strengths related to the aerospace and oil and gas industries also directly map to areas where the Canadian economy shows a relatively high level of specialization (i.e., aircraft and spacecraft manufacturing and mining and quarrying, which in this case includes oil and gas). These relationships are plausible and suggest connections between Canada's S&T strengths, IR&D activities, and industries of particular economic importance to Canada. More research, however, is required to further validate, document, and explore these relationships.

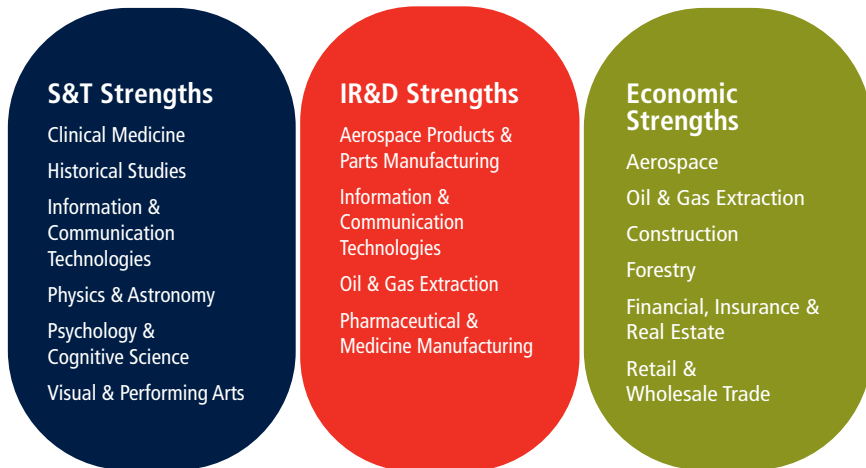


Figure 7.1

Alignment of Canadian S&T, IR&D, and Economic Strengths

To determine the degree of congruence, the figure maps the S&T strengths identified by CCA (2012a), the IR&D strengths identified in Chapter 6, and the economic strengths identified above.

While these four alignments demonstrate that there is some congruence between S&T, IR&D, and economic strengths, what is perhaps more important is the degree to which there is limited alignment. For instance, while there is a degree of specialization in the Canadian economy in forestry, there does not appear to be strong S&T or IR&D in this industry. The remainder of this chapter considers to what extent this lack of alignment is a result of different incentives in the production of public and private knowledge (a universal feature), and Canadian S&T and innovation policy and knowledge translation barriers (Canada-specific features).

7.2 THE PRODUCTION OF KNOWLEDGE: A TALE OF TWO INCENTIVE STRUCTURES

At a fundamental level, knowledge has two essential properties that make it what economists call a public good: it is non-rival and non-excludable (Romer, 1990; Jones, 2005). First, being non-rival implies that the use of an idea by any given individual does not preclude the use of the same idea by any other individual. In other words, the stock of knowledge is not depleted when it is shared and multiple individuals can use an idea at roughly zero cost (Howitt, 2000). By comparison, if more than one person wishes to use physical capital, more than one piece must be produced (e.g., two people cannot use the same shovel or computer at the same time). Second, non-excludability implies that once an idea is made public, others cannot be easily excluded from its use. For example, since the development of Newton's calculus or Ford's assembly line, many others have used (and improved upon) these ideas to build bridges, manufacture iPhones, and the like. In both senses, knowledge is fundamentally different than physical capital – it can be shared and used simultaneously while physical capital is specific to its owner (CCA, 2009). A cornerstone of economic theory is that markets provide poor incentives for the production of knowledge. The non-rival nature of knowledge means that if and when it is produced, the market will fail to provide the socially optimal quantity (since the cost of additional user is zero). Moreover, the non-excludable nature of knowledge invites free riders to make use of the knowledge without contributing to its development. The producers of knowledge cannot capture economic returns, leading to sub-optimal production.

As Howitt (2000) remarked, “Fortunately, the world does not operate through markets alone.” When markets do not function efficiently, other institutional incentive structures frequently emerge. This is the case for the production of knowledge, where two parallel sets of institutional arrangements have emerged in most advanced economies: open science, in which nonmarket reward structures provide the incentives for scientists to produce and share knowledge; and the patent system, in which market forces are constrained by legal restrictions on

intellectual property. Both systems provide a partial solution to the dual problem of producing and sharing knowledge; however, both systems provide different incentives, which leads to the production of fundamentally different types of knowledge (Howitt, 2000). The type of knowledge produced by open science (i.e., in universities and government labs) is often not the type of knowledge that can be easily used by the private sector. Ultimately, the translation of science into firm innovation and economic growth is constrained by the different incentive structures in the public and private sectors.

7.2.1 Publicly Produced Basic Knowledge

Sociologist Robert Merton (1957, 1968) advanced the notion that the goal of scientists, whether in universities or government labs, is to establish “priority of discovery” by being first to communicate an advance in knowledge. The reward is the *recognition* for being first by the scientific community. The recognition awarded priority has varied forms, depending upon the importance the scientific community attaches to the discovery. Eponym — the practice of attaching the name of the scientist to the discovery — is the most prestigious form of recognition, with examples ranging from the Copernican system and Planck’s constant to Hodgkin’s disease and the Higgs particle. Recognition also comes in the form of prizes such as the Nobel Prize, Fields Medal, Lemelson-MIT prize, NWO Spinoza Prize and others. Finally, while a lesser form of recognition, publication is a necessary step in establishing priority. Publication counts and impact are often important indicators of the state of science in a particular jurisdiction or the productivity of an individual scientist (CCA, 2012b). Financial remuneration, tenure, and other forms of career progress are also largely determined by these outcomes of priority discovery (Stephan, 2010).

Whatever the form of recognition (eponymy, prizes, or publications), priority of discovery is established by being first. This priority-based incentive structure induces scientists to publish quickly and devote energy to establishing priority over rival scientific claims. That is, they must “publish-or-perish.”⁶⁶ While not always the case, this leads to something of a double-edged sword. On the one side, rapid publication of ideas solves the problem caused by the non-rival and non-excludable nature of knowledge: scientists are incentivized to produce and widely share knowledge. On the other side, the type of knowledge produced is often not immediately marketable or easily used by the private sector; rather, it

66 For instance, Merton (1968) documents the extreme measures Newton took to establish that he, not Leibniz, was the inventor of calculus, and it is widely accepted that Charles Darwin’s rapid publication of *The Origin of Species* established him as the father of evolution over Alfred Wallace.

is fundamental in nature and prized as a contribution to the academic literature. This by no means undermines the creativity or impressiveness of an idea, but rather simply implies it is not immediately destined for the market.

7.2.2 Privately Produced Knowledge

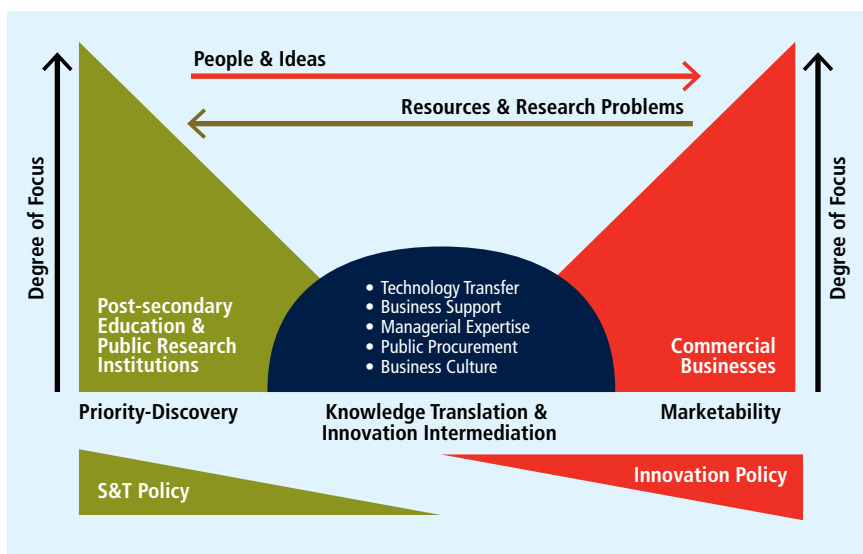
Given the market on its own cannot protect ideas developed in firms, the patent system has evolved to provide the incentive for firms and individuals to produce knowledge and earn profit. Under the patent system, a firm can receive a patent that prohibits any competitor from a like product or process without the patent-holding firm's permission. Compared to situations where unrestricted competition drives profits to zero, this "selective elimination of competition" provides firms with incentives to produce novel products and processes (Howitt, 2000). While other mechanisms do exist to protect ideas (e.g., industrial secrets) or combat competition (e.g., first-to-market races), the patent system provides greater incentives to share knowledge. In short, the patent system — much like the priority-based incentive structure, albeit via a different mechanism — creates incentives to produce and share private knowledge.

While the priority-based incentive drives the "publish-or-perish" mantra of universities, there is a growing pressure on universities to contribute directly to innovation by engaging in applied research and providing industry with technical solutions or devices that have immediate relevance. This pressure is placing a growing emphasis on universities to fulfil this type of knowledge production by commercializing their own academic inventions. This requires involvement in the creation and management of intellectual property (IP) rights and entrepreneurial activities such as the foundation of new firms. A major witness of this change is the wave of legislation aimed at encouraging universities to take patents and license them under profitable conditions, starting in the United States with the *Bayh-Doyle Act* of 1980 and the imitations of this Act in several European countries (Jaffe & Lerner, 2006).

S&T, often characterized as "discovery research," is performed in both the public and private sectors. S&T performed in the private sector is typically aligned with IR&D, as private-sector resources are primarily invested in market-driven research and development activities. In addition, many public research organizations (e.g., National Research Council, provincial research organizations) also focus on market-driven research that aligns well with IR&D and the other needs of business. Conversely, S&T performed in universities is primarily driven by scientific curiosity, resulting in lack of alignment between public-sector S&T efforts and the needs of IR&D.

7.3 CANADIAN S&T AND INNOVATION POLICY

The Government of Canada has long recognized the importance of S&T, IR&D, and innovation to the economic and social progress of the country. This is reflected in a long-standing and significant set of investments across the entire knowledge generation continuum (see Figure 7.2), ranging from discovery grants and the National Research Council to sector-specific business subsidies and the Scientific Research & Experimental Development (SR&ED) tax credit program. It has, however, been argued recently that the balance of support is tipped towards the discovery-based research conducted in universities, colleges, and public research organizations (Industry Canada, 2011a; Miller & Côté, 2012; OECD, 2012a).



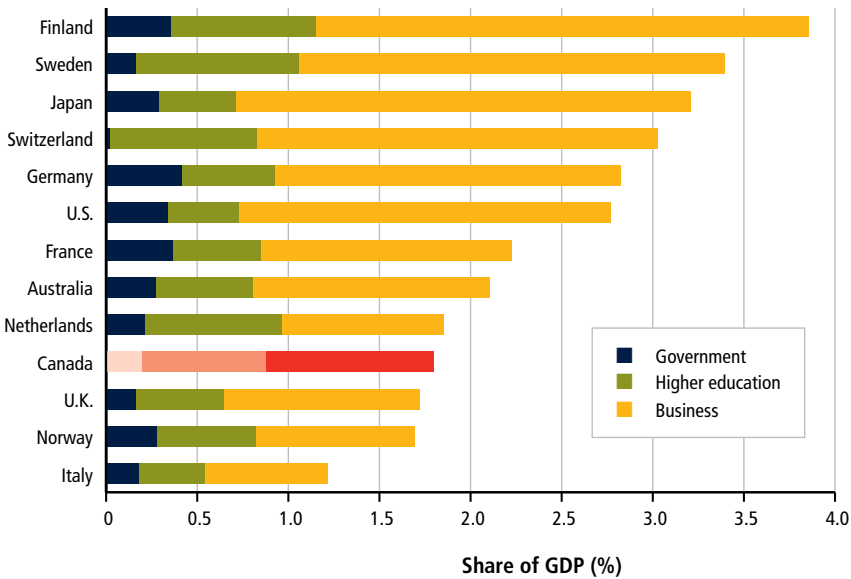
Source: Adapted from Nicholson (2011) and Industry Canada (2011a)

Figure 7.2

The Knowledge Generation Continuum and Policy Complementarities

The horizontal axis represents the knowledge generation continuum from discovery research on the left to market-facing development on the right. The basic idea is that the focus on post-secondary education institutions and public research organizations (the green triangle) declines as knowledge generation shifts away from basic research while the focus of business declines as knowledge generation shifts away from market-focused development. The blue bubble in the centre represents a set of factors that enable (inhibit) the coordination of the knowledge generation efforts of public researchers and industrial firms. The green triangle and the adjacent inverse red triangle highlight that although S&T and innovation policy are complementary, they are *distinct* policy approaches.

This perspective is supported by the international data. In 2010, R&D expenditures in higher education (HERD) amounted to just under 0.69 per cent of GDP, the seventh highest rate in the OECD and more than twice the rate of the United States (OECD, 2012a).⁶⁷ By contrast, Canada ranked 20th among OECD countries in overall IR&D intensity in 2010, spending at less than half the rate of innovative economies like Finland and Sweden. As highlighted in Figure 7.3, which breaks down R&D spending by performer, there is remarkable similarity in the amount of R&D performed by the higher education and government sectors combined: from 0.54 per cent of GDP in Italy to 1.15 per cent in Finland. What separates world-leading jurisdictions is the amount of R&D performed by business, with a range of 0.67 per cent of GDP in Italy to 2.70 per cent in Finland. Canada compares favourably with these comparator countries on higher education and government combined spending (0.88 per cent), but lags well behind the leading countries in business spending (0.92 per cent).



Data source: OECD (2013)

Figure 7.3

R&D Intensity by Performer, G7 and Selected OECD Countries

This figure shows expenditure on R&D by the government, higher education, and business sectors as a share of GDP for a set of countries in 2010 (or latest year for which data are available).

⁶⁷ Approximately three per cent of HERD is funded by the business sector in Canada. This compares with the OECD average of one per cent.

The interpretation of these data is critical. It is not that Canada performs *more* R&D in the public sector than comparator jurisdictions, but rather that Canada performs *less* R&D in the business sector than leading jurisdictions. This implies public policies designed to encourage business R&D and not necessarily a redistribution of resources away from research conducted in universities. Ultimately, obtaining the full economic benefit from the strong state of Canadian S&T (CCA, 2012a) requires a vibrant business sector. In the United States, the President's Council of Advisors on Science and Technology (2012) argued that university research can "benefit the Nation only insofar as these accomplishments are effectively coupled to the needs of a strong private sector."

As highlighted in Section 7.2, although the priority-based incentive structure tends to lead to the production of scientific knowledge (the green triangle in Figure 7.2) that is not easily translated into marketable innovations, in doing so, it produces well-trained graduates who can directly translate S&T into innovation. Arguably this is the most important activity of universities. These individuals, whether scientists, engineers, management, or other professionals, translate research findings, engage in development activities, and supply the business acumen needed to assess market demand and commercialize ideas. In keeping with this, Miller and Côté (2012) remarked:

Universities are generally concerned by the lack of connections between professional research and economic development in the surrounding region. They should not be. Their most important role in local development is not generation of new knowledge, but their ability to attract talent and, through that talent, to disseminate leading-edge knowledge in the local economy. But to attract the best and brightest and properly train them, they need to conduct leading-edge research. So universities should continue to orient their research toward the pursuit of Nobel prizes and peer-review publishing and in the process expose their students to leading-edge ideas. This is what they're good at.

This is in stark contrast with the market success incentives that drive businesses to innovate: to develop new products, processes, and methods of organization and marketing that drive competitiveness and profitability.

The fact that the public and private sectors respond to different incentives and produce different types of knowledge implies that different types of policies are required to support both sectors. As depicted in Figure 7.2, while S&T policy and innovation policy are complementary, they are *distinct* policy approaches. On the one hand, S&T policy supports the production of basic and applied knowledge through direct research funding and early stage commercial support.

For instance, most Canadian universities have dedicated technology transfer offices and sophisticated royalty regimes, licensing agreements, and spinoff protocols in place to enable scientists to take their ideas to market. On the other hand, innovation policy supports the production of commercial knowledge, through a mix of direct and indirect business support, and creates market signals via procurement, competition, and other industrial-type policies. While a strong S&T base is essentially a prerequisite for an innovative private sector, IR&D and business innovation are driven by incentives and policies that are quite different from those that drive public researchers. The Panel considers it critical that this fundamental distinction is recognized in design and implementation of public policies. The next section discusses five Canada-specific barriers that inhibit the translation of S&T knowledge into innovation and wealth creation.

7.4 CANADIAN BARRIERS TO KNOWLEDGE TRANSLATION

Section 7.2 elucidated how the incentive structures facing scientists (priority-based) and firms (profit-based) drive the type of knowledge produced. The critical point was that the priority-based incentive structure in the public sector often generates knowledge that is prized as a contribution to the academic literature rather than knowledge with immediate market potential. This is only part of the story for two reasons. First, promising ideas developed in universities do, in fact, make it to market in some cases. Second, the incentive structure present in universities is not particular to Canada, but present in most universities across the globe. Given the limited alignment between strong Canadian S&T performance and relatively weak business R&D and productivity performance, there must be other factors at play.

Competition is among the principal drivers of business innovation as firms seek to increase profits and market share, and distinguish themselves from their competitors (Schumpeter, 1942). Empirically, the relationship between competition and innovation is an “inverted-U shape:” greater competition first increases, and then decreases, the rate of innovation (CCA, 2009). The basic idea is that, on the one hand, firms have little incentive to innovate if they are not stimulated by competition. Competition drives firms to stay ahead of their competitors by developing new and better products. On the other hand, with too much competition, firms are dis-incentivized to innovate since the potential profits of innovation will be eroded through excess competition (CCA, 2009; OECD, 2009a).

In Canada anecdotal evidence suggests that many industrial sectors face less intense competition than in the United States and other peer countries (CCA, 2009). Moreover, data suggest that corporate profitability, before taxes and taken at the aggregate level, is higher in Canada than in the United States (CCA, 2009). Neither

low levels of competition or high profitability do much to encourage Canadian firms to engage in IR&D and innovation to the same extent as undertaken in other countries. In colloquial terms, Canadian industry is “fat-and-happy,” content with the status quo. The promising ideas that are “pushed” out of universities are not something Canadian businesses are incentivized to “reach back” for.

In addition to competition, the Panel identified five Canada-specific barriers to translating S&T knowledge into innovation and wealth creation that are prominent in the academic and public policy literature.

7.4.1 Technology Transfer

The apparent inability to capitalize on Canada’s strength in S&T may leave much potentially useful knowledge unexploited. Many Canadian universities have dedicated technology transfer offices (TTOs) that help faculty members translate their ideas into commercially viable products. TTOs connect faculty with sources of financing and individuals experienced in developing strong business models (e.g., finding customers; cultivating a market; learning accounting, finance, human resource, and operational skills; managing intellectual property; securing regulatory approvals; and developing a global mindset); and organize conferences, seminars, and additional networking tools such as websites, directories, and newsletters. The resulting spin-off firms are often a source of “big ideas” that have the potential to be revolutionary and disruptive, often creating entirely new markets (Brzustowski, 2012). These firms are a source of economic dynamism and competitive pressure as they offer consumers innovative new products and drive established firms to rethink their market strategies (Action Canada, 2011).

Since the early 2000s, while investments in university research and technology transfer personnel have increased sharply, the number of patents and licensing agreements has risen much less dramatically (CCA, 2009, 2012a). According to the OECD (2012a), this may suggest “low and declining productivity of technology transfer.” Agrawal (2008), for instance, attributes this to a weak commercialization culture at universities, partially driven by an “overly bureaucratic mindset” across TTOs (OECD, 2012a).

Colleges play a role in knowledge and technology transfer (CCA, 2013). By offering applied training programs, they produce individuals with technical skills for IR&D: technicians, technologists, design specialists, and marketing specialists. Colleges often have strong industry connections and applied research capabilities that help solve technical challenges encountered during production (Brzustowski, 2012; CCA, 2013).

7.4.2 Managerial Expertise

It is often argued that there is a dearth of management experience and business acumen in Canada (ICP, 2009). Turning an idea into an innovation rests heavily on the strength of a business model: finding customers; cultivating a market; learning accounting, finance, human resource and operational skills; managing intellectual property; securing regulatory approvals; and developing a global mindset. Without well-trained and experienced management, even the most inventive and ingenious ideas may sink on their voyage to market.

Canadian managers have lower levels of educational attainment than their U.S. counterparts (CCA, 2009; ICP, 2009). Only 35 per cent of Canadian managers possess a university degree compared with 53 per cent of U.S. managers. Furthermore, a much larger percentage of Canadian managers (39 per cent) possess some post-secondary education relative to the United States (26 per cent), implying that Canadian managers are more likely to leave post-secondary education without obtaining a degree. This could stem from any number of reasons, and requires additional research.

The OECD suggests that Canada's persistent productivity gap relative to the United States is partially the result of managerial, commercialization, and organizational skills, rather than scientific human capital (OECD, 2012a). The comparatively low managerial skill set impedes Canada's ability to compete in fast-paced knowledge-driven economies and to adequately meet the needs of dynamic markets (ICP, 2009). Not only are better-educated managers more likely to have exposure to advanced technologies, they are also more likely to possess the managerial techniques essential to capitalizing on ground-breaking work.

7.4.3 Business Support

Many new ventures face the significant challenge of securing sufficient start-up and risk capital (Industry Canada, 2011a). Conventional wisdom suggests that the cost of commercializing an idea is orders of magnitude more expensive than idea generation itself (Brzustowski, 2011). In Canada many firms are able to secure relatively small amounts of early-stage seed capital from a variety of regional, provincial, and/or federal programs. Since this funding support is significantly less generous than elsewhere (e.g., Small Business Innovation Research (SBIR) grants in the United States), individual (angel) investors and venture capitalists are essential components of the Canadian start-up ecosystem. As a technology or business model progresses from proof-of-concept to demonstration to early commercialization and faces the so-called "valley of death," angel investment and venture capital (VC) financing are critical for converting the fruits of IR&D

into economic value (CCA, 2009, 2013; Action Canada, 2011). In Canada both aggregate VC investment and the number of firms receiving VC investment have been falling over the last decade (CCA, 2009; ICP, 2011).

Implicit in the discussion of the nature of knowledge (non-rival and non-excludable) is a justification for public funding of innovation activities. It is argued that governments have a role in incentivizing innovation by correcting this market failure by compensating for the gap between the private and social returns in the production of knowledge (Czarnitzki *et al.*, 2011). In practice, direct subsidies and indirect tax incentives are two key approaches to funding direct investments in innovation production. An extensive economics literature examines the relative merits of these approaches and offers empirical evidence of the factors that determine the most appropriate approach. The evidence is mixed (Mamuneas & Nadiri, 1996; Parsons & Phillips, 2007). Nonetheless, the heavy reliance in Canada on indirect support (i.e., SR&ED tax credit) has been suggested as a root cause of Canada's poor record of innovation (Industry Canada, 2011a; OECD, 2012a). Business R&D and innovation activities can also be supported with in-kind assistance of equipment and facilities and networking opportunities (Dalziel *et al.*, 2012). Box 7.1 describes how innovation intermediary MaRS supports the R&D and innovation efforts of a large number of firms, resulting in increased firm revenues, job creation, and other economic benefits.

7.4.4 Public Procurement

As noted by OECD (2012a), a significant challenge for innovation is the lack of a receptor market for new products and processes. In Canada few demand-side policies encourage innovation by creating markets for these products and processes (Miller & Côté, 2012). The recent Jenkins report (Industry Canada, 2011a) suggests using public procurement as a lever to create demand. Especially in markets with public-good properties and high innovation propensity (e.g., health, education, environment), procurement tenders and platform technologies (CCA, 2013) can be designed to foster innovation. The difficulties of assessing end demand aside, by creating a market for innovative products and processes the government creates an incentive for innovation. With these types of incentives, firms are more likely to “reach back” for ideas emanating from university-led S&T.

7.4.5 Business Culture

Perhaps owing to historical antecedents (Nicholson, 2012) and general aspects of Canadian culture (CCA, 2009), Canadian business culture is highly risk averse. A recent Deloitte (2012) report argues that “[p]erhaps the most significant factor contributing to the lackluster growth of Canadian firms is an inability to overcome risk and uncertainty.” The results of a survey of 450 Canadian and 452 U.S.

Box 7.1**MaRS**

In 2000, a group of private individuals invested over \$14 million of private capital with the goal of creating a nucleus of companies in Toronto in the medical and related sciences industries (MaRS, 2013). MaRS, as the embodiment of this effort became known, leveraged these initial funds to ultimately secure over \$600 million in investment from the private sector; the municipal, provincial, and federal governments; Cancer Care Ontario; and the University of Toronto. In 2008–2011, the companies of the MaRS cluster raised over \$500 million in capital, earned nearly \$300 million in revenue, and created over 2,600 new jobs. These results reflect the benefits of clusters to their constituent companies and the economies of the regions and nations where clusters are located (MaRS, 2013).

MaRS is an interesting example of an innovation intermediary (CCA, 2013). It was “purpose-built” to capitalize on the local pool of world-class hospitals and universities, highly respected internationally for achievements in discovery research. As such, it clearly had a broad and solid foundation. The aim of MaRS was to build on those strengths in value creation and simultaneously address weaknesses in the existing innovation ecosystem on the value capture side (IR&D through to successful commercialization). Initially, it was intended to comprise life science and healthcare-related companies. Early on, however, it attracted companies in information technology, communications and entertainment (ICE), and cleantech and advanced materials. Of the more than 1000 companies associated with MaRS in 2012, approximately 60 per cent were in ICE, 20 per cent in life science and healthcare, 15 per cent in cleantech, and 5 per cent in social innovation.

MaRS has evolved and expanded, but stayed true to its strategy of focusing on ventures that reflect the intersection of local/MaRS expertise (especially scientific and technological), Canadian innovation, market opportunity, and high potential social and economic impact. In its early days healthcare and life sciences, ICE, cleantech and advanced materials emerged from this strategy; social innovation was intentionally added in 2007. A number of companies today work at the intersection of these sectors, such as in health ICT (ICE and healthcare), education (ICE) and social innovation.

business leaders showed that Canadian business leaders were substantially more risk averse than their U.S. counterparts. Moreover, the 2011 Industry Canada *Survey of Innovation and Business Strategy* found that the principal barrier to innovation was risk and uncertainty for 47 per cent of the 6,233 firms with more than 20 employees (Industry Canada, 2011b). Given that the ideas emanating from university-led S&T are often further away from market and therefore inherently more risky, it is perhaps not surprising that Canadian businesses have a low propensity to “reach back” for them.

7.5 CONCLUSION

This chapter demonstrates, in general, limited alignment between areas of S&T, IR&D, and economic strength. The Panel, however, identified four areas of some congruence: clinical medicine S&T and pharmaceutical IR&D, information and communication technologies S&T and IR&D, oil and gas IR&D and economic performance, and aerospace IR&D and economic performance.

The lack of alignment may be the result of different incentives in the production of public and private knowledge and Canada-specific factors. First, the incentive structures present in universities, colleges, and public research organizations (priority-based) often lead to development of knowledge that is prized as a contribution to the academic literature rather than knowledge with immediate market potential. This leads to a situation where, as Griliches points out, “[m]ost of the economy is quite far away from the boundaries of the current state of knowledge” (Krueger & Taylor, 2000).

Second, given that some ideas do make it to market and other countries seem to make better use of their S&T knowledge bases, it would appear there is something specific in the Canadian context. According to the literature, five potential barriers to the translation of S&T into innovation and wealth creation are: technology transfer, business support, managerial expertise, public procurement, and business culture. The Panel concluded that there was insufficient empirical evidence to determine which of these barriers is most critical in Canada. As such, further research must be conducted to tease apart the relative impact of these factors; however, the Panel firmly believes that none of these factors are immutable. With a strong commitment from all stakeholders — universities, industry, and government — all these factors can be overcome. This will enable Canada to more effectively exploit its S&T knowledge base, improve the vitality of innovation, increase economic performance, and further enhance the social progress of the country.

8

Conclusions

- **The State of Industrial R&D in Canada**
- **Canada's IR&D Strengths**
- **Alignment of IR&D Strengths with S&T and Economic Strengths**
- **Final Remarks**

8 Conclusion

The charge to the Panel asked: *What is the state of industrial R&D in Canada?* The answer to this question, and to the three sub-questions, forms much of the content of this report. This chapter consolidates and summarizes the Panel's responses.

8.1 THE STATE OF INDUSTRIAL R&D IN CANADA

What is the state of industrial R&D in Canada?

Many of the key facts about Canada's record of industrial R&D (IR&D) are well known. Expressed as a share of GDP, IR&D expenditures in Canada are both low and declining. This decline comes, in part, from reductions in spending by some of Canada's major corporate R&D sponsors (e.g., Nortel Networks), but IR&D spending has declined more broadly in many industries. Such declines stem, in part, from an overall shift in the Canadian economy. The share of Canada's economy accounted for by manufacturing, which is, on average, more IR&D intensive than other sectors, has shrunk in recent years. The result is an economy that is less IR&D intensive overall. Although Canada's overall industrial structure (such as the size of the resource economy) does not fully explain low levels of IR&D in the economy, the small share of the economy accounted for by those few highly IR&D-intensive industries affects Canada's overall investment in IR&D.

Canada produces 4 per cent of the world's scientific journal articles, and Canadians are responsible for 1.1 per cent of the high-quality patents filed in Europe, the United States, and Japan. Canada also accounts for a relatively large share of world patents in pharmaceuticals and medicines (drugs) and communications technologies. In addition, research on the impact of Canadian patents suggests that they are of relatively high quality. Canadian industry patents are cited in other patents roughly 20 per cent more than the world average.

These findings are broadly consistent with many previous studies on Canada's IR&D capacity and innovation performance. This report also contains a number of other findings.

First, the number of IR&D personnel as a proportion of the population in Canada is roughly on par with the norm for OECD countries. Given the low level of IR&D investment, Canadian IR&D is relatively personnel intensive compared to its peers, and the implicit wages for Canadian IR&D personnel are

lower. There are several potential reasons why wages are relatively low, but the low rate of capital investment is in line with other analyses that suggest broader under-investment in machinery and equipment in Canada.

Second, international comparisons of IR&D intensity by industry suggest that Canadian high-technology industries, by and large, invest in IR&D at similar levels to those of their peers in other countries. This pattern, however, is not reflected across all industries. Although Canadian computer and communications equipment manufacturing industries have comparatively high IR&D intensities, the Canadian aerospace industry has comparatively lower IR&D intensity. These IR&D-intensive industries constitute a smaller part of the economy in Canada compared to in the United States, and this smaller relative size drags down Canada's overall IR&D intensity.

Although it is encouraging that more firms are undertaking IR&D in Canada over recent years, the average size of a firm performing IR&D in Canada is smaller than in other countries. Given the likely economies of scale in IR&D, a broader balance of firms across size classes performing IR&D in Canada would likely benefit overall IR&D performance.

Third, innovation surveys in Canada and abroad found that Canadian firms repeatedly report relatively high levels of innovation compared to firms in other countries in contrast to their relatively low expenditures on IR&D. Despite methodological questions about the international comparability of these types of data, these findings suggest that Canadian firms do not rely on IR&D to generate innovation as much as in other countries. Innovation comes from other sources such as organizational change. It is less clear that Canadian firms perform as well in translating innovation into additional sales.

8.2 CANADA'S IR&D STRENGTHS

What are Canada's industrial R&D strengths? How are these strengths distributed across the country? How do these trends compare with what has been taking place in comparable countries?

Data limitations argue for caution when forming judgments about the relative strengths or weaknesses of IR&D in certain industries. In particular, the Panel suspects that too much IR&D is assigned to the service sector in Canada and not enough to manufacturing because of Statistics Canada's classification methodologies. Nevertheless, based on the best available evidence, the Panel identified four industries of IR&D strength in Canada:

- Aerospace products and parts manufacturing
- Information and communication technologies (ICT)
- Oil and gas extraction
- Pharmaceutical medicine manufacturing

These industries demonstrate strength by multiple measures, including those of magnitude and intensity, quality and impact, and trends. They all account for a substantial share of total Canadian IR&D, and have high levels of impact on at least one of the key IR&D outputs (patents or publications). There are, however, differences both within and across these industries. Not all ICT industries show similar patterns of strength. Some, such as computer systems design and related services, show strength across nearly all measures. Others, such as communications equipment manufacturing, show high levels of impact on patents and publications, but have experienced declining IR&D expenditures and economic output in recent years. The aerospace industry accounts for a large share of world aerospace exports; however, the impact of its IR&D, based on patent and publication citations, is only average. The oil and gas industry has a high level of impact based on patent citations and has seen rapid growth in both IR&D expenditures and economic output. While the pharmaceutical industry also shows strength on several measures of magnitude and impact, it has experienced declining IR&D expenditures over the past decade.

The resulting picture of IR&D activity is complex, with varying strengths and weaknesses within, as well as across, industries. IR&D intensity in these four industries is comparable to those in other large industrialized economies with IR&D intensity particularly high in the mining and oil and gas industry. In contrast to the experience in other large economies, IR&D intensities in pharmaceuticals and ICT weakened in Canada over the last decade. With the exception of the oil and gas extraction industry, those industries that display IR&D strengths in Canada are generally smaller as a share of the economy than in countries with more diversified research bases. Although IR&D activity levels are small in scale for many industries linked to resource extraction, growing IR&D intensities suggest that critical innovations are also taking place in industries linked to Canada's historic comparative advantage.

Firms locating their IR&D facilities in close proximity can be a powerful driver of IR&D as neighbouring firms learn from and compete with each other. To assess the regional distribution of IR&D strengths in Canada, the Panel examined the provincial distribution of IR&D strength and activity. Based on these data, IR&D activities across all industries tend to concentrate in Ontario and Quebec.

In fact, across the four industries of IR&D strength identified by the Panel, these two provinces accounted for roughly three-quarters of total IR&D expenditures. Nonetheless, the distribution of IR&D activity in these industries varies considerably:

- *Aerospace*: Around three-quarters of all IR&D takes place in Quebec, and most of the remainder in Ontario.
- *ICT*: IR&D for almost all industries is most heavily concentrated in Ontario, with Quebec accounting for the highest share of computer and electronic product manufacturing. British Columbia also has a relatively high share of IR&D, particularly in computer and peripheral manufacturing, semiconductors, and computer system design and related services.
- *Oil and gas*: The regional distribution of IR&D is unclear due in part to data suppression to protect firm anonymity. The distribution of patenting activity, however, shows that the majority of IR&D most likely occurs in Alberta, with a substantial share in British Columbia.
- *Pharmaceuticals*: IR&D activities are distributed mainly across Ontario and Quebec with British Columbia accounting for most of the remainder.

There is evidence that other provinces exhibit IR&D strengths in other industries (for example, the Atlantic provinces show strength by several indicators in food and beverage manufacturing). These provinces, however, account for only a small portion of the IR&D associated with Canada's four industries of IR&D strength, as discussed above.

Clusters of IR&D strength can generate valuable spillovers across firms, which attract further investment and build positive feedback effects. To take advantage of these effects, firms investing in IR&D will inherently tend to concentrate their investments. Despite the degree of concentration of IR&D in a few provinces in Canada, it is even more concentrated geographically in economies outside of North America.

8.3 ALIGNMENT OF IR&D STRENGTHS WITH S&T AND ECONOMIC STRENGTHS

In which scientific disciplines and technological applications are our relative strengths most aligned with Canada's economic strengths or industry needs? What are the key barriers and knowledge gaps in translating Canadian strengths in S&T into innovation and wealth creation?

The Panel found limited alignment between Canada's areas of S&T strength, IR&D strength, and overall economic strength. The Panel used the six research fields identified as S&T strengths in the 2012 report of the Expert Panel on the

State of S&T in Canada. Since no widely agreed-upon methodology to determine a country's relative economic strengths exists, the Panel examined industries based on three criteria: those comprising a large average share of Canadian GDP; those comprising a large share of the Canadian economy in comparison with other countries; and those with higher than average growth rates.

There are some areas of congruence. Canada's research strength related to clinical medicine may contribute to the strength of the pharmaceutical and medicine manufacturing industry. Likewise, Canada's research strength in ICT also enhances IR&D relating to these technologies. Canada's IR&D strengths related to the aerospace and oil and gas industries also directly map to areas where the Canadian economy shows a relatively high level of specialization (i.e., aircraft and spacecraft manufacturing and mining and quarrying, which in this case includes oil and gas). These relationships are plausible and suggest connections between Canada's S&T strengths, IR&D activities, and industries of particular economic importance to Canada. However, more research is required to further validate, document, and explore these relationships.

While there are areas of alignment between Canada's S&T strengths, IR&D strengths, and areas of economic specialization, no clear relationships exist between activities. Limited congruence between S&T, IR&D, and economic strengths, however, is in part to be expected because of the inherently complex, dynamic, and non-linear nature of these relationships and the different incentives for production of knowledge in the public and private spheres.

One of the critical components of an effective system is strong demand for innovative products. Not only must there be a plentiful supply of skilled workers and ideas from higher education, but demand for these critical inputs must also be strong. A common theme in the literature is that insufficient competitive intensity in the Canadian economy limits demand for innovation, and in turn for IR&D. Firms may invest less in IR&D without the imperative to develop new products and lower costs to survive and prosper, or to use new technologies to improve their competitiveness.

The Panel also identified five barriers to translating S&T knowledge into innovation and wealth creation that have been advanced in the academic and public policy literature for the Canadian context:

- *Technology transfer*: Low rates of growth in patents and licensing agreements at Canadian higher education institutions, relative to new investments in research and technology transfer personnel, suggest existing technology transfer processes are not effective.

- *Managerial expertise:* Evidence suggests that Canadian managers have lower levels of education than their counterparts in the United States; and consequently that managerial, commercialization, and organizational skills may play a role in Canada's record of comparatively low productivity growth.
- *Business support:* New ventures in Canada receive relatively little direct public funding support for development and commercialization of new technologies. Unlike other countries, the majority of public support for IR&D in Canada is provided through tax credits, rather than direct investment.
- *Public procurement:* Relatively few demand-side policies in Canada encourage IR&D by creating markets for new technologies, products, or services.
- *Business culture:* Canadian business leaders are risk averse relative to their U.S. counterparts. As a result, Canadian firms may be less likely to take on the risks associated with translating new research discoveries into commercial products and/or using new technologies.

8.4 FINAL REMARKS

IR&D is a cornerstone of long-term sustainable economic growth. Canada benefited from rising resource prices over the last decade, but the headwinds of an aging population and uncertainty about future demand for those resource exports mean that productivity growth will be central to a thriving and prosperous Canada in the future. A competitive business sector that invests in the technologies of tomorrow through IR&D is key to improved productivity. Investment in IR&D benefits business, the region in which the IR&D takes place, and the economy at large. A strong foundation of IR&D in Canada ensures the capacity to develop and adopt world-leading technologies so that Canadian firms can compete in a global economy centred on knowledge and technology.

Despite overall weakness by many measures of IR&D, Canada has substantial IR&D strength in several industries, and it appears that many smaller firms are developing strategies to invest in IR&D. With Canada's strong post-secondary education system and a foundation of world-class university research, the underpinnings for robust investment in IR&D exist. But attempting to connect such scientific strength and IR&D in a direct, linear relationship is overly simplistic, particularly as the IR&D-intensive industries form a smaller part of the Canadian economy than of other advanced economies. Improving Canada's IR&D performance requires broadening the demand for IR&D across larger firms and attracting new investment. Canada's IR&D intensity will be strengthened by reinforcing firms' imperative to invest to ensure their own future survival, success, and profits. In this respect, increasing the competitive intensity of the economy will create demand for more innovation and, in turn, IR&D.

Box 8.1**Enhancing the Evidence Base of the State of IR&D in Canada**

Improving the quality and comprehensiveness of the evidence base for IR&D in Canada is an important research objective going forward. Some examples of avenues that could be explored in the future include:

- **Improved assignment of R&D measures to industry:** Steps could be taken to develop alternative processes for assigning R&D expenditures (and personnel) across industries to result in a more informative picture of R&D activity.
- **Improved timeliness of internationally comparable data on IR&D intensities:** Canada could work with its partners in the OECD to improve the timeliness of IR&D expenditure and intensity data.
- **Monitoring of industry publication and patent data over time:** Long-term strategies could be developed for monitoring industry patent and publication data over time.
- **Additional qualitative measures of IR&D capacity:** New survey-based studies could be conducted to provide additional information on the perception of Canadian IR&D in the global research and technology community.
- **New studies of geographic clustering of R&D activities related to specific industries:** Existing data on R&D expenditures and related variables do not allow for sufficiently fine-grained analysis of geographic clustering of R&D activities. More industry-specific studies could fill the gap.
- **More sector- and industry-specific studies of R&D performance and industry needs:** New studies could examine R&D performance in sectors and industries in relation to perceptions of industry needs.

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Appendix A
Bibliometric and Technometric Methodology

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Bibliometric and Technometric Methodology

To inform the current assessment of industrial R&D (IR&D) in Canada, Science-Matrix was commissioned to produce statistics on the scientific output (bibliometrics) and patenting activities (technometrics) of Canadian firms. The goal of this exercise was to produce bibliometric and technometric data for the different industries. It involved linking the Canadian firms that have produced scientific publications or have been granted patents in the last 10 years with their North American Industry Classification System (NAICS) industries.

To produce in-depth and robust statistics on the scientific output and patenting activity of Canadian firms, their scientific publications must be retrieved from Scopus, and their patents from the United States Patent and Trademark Office (USPTO) database. Company names must be standardized in Scopus and the USPTO database, and all variant names standardized under a single name. Subsequently, a NAICS code must be assigned to each company by mining Industry Canada company directories, and manual internet searches.

IDENTIFICATION OF FIRMS IN SCOPUS AND THE USPTO DATABASE

The first step was to identify all Canadian addresses related to firms in Scopus and the USPTO database. Scopus lists 375,000 different Canadian addresses for scientific papers published between 2003 and 2010. These addresses are not standardized, and addresses from firms are not pre-identified in the database. Some examples of addresses in Scopus include:

- Department of Mathematical and Statistical Sciences, University of Alberta, Edmonton, Alta. T6G 2G1
- Department of Medical Biophysics, University of Toronto, Ontario Cancer Institute, Toronto, Ont. M5G 2M9
- Department of Medical Genetics and Microbiology, The Terrence Donnelly Centre for Cellular and Biomolecular Research, University of Toronto, Toronto, Ont. M5S 3E1
- Department of Medicine, University of Toronto, Toronto, Ont.
- Department of Pharmacy, Hospital for Sick Children, Toronto, ON
- Department of Rehabilitation Sciences, Faculty of Medicine, University of British Columbia, Vancouver, BC
- Dept. of Anthropology and Sociology, University of British Columbia
- Dept. of Elec. and Comp. Eng., University of Waterloo, Waterloo, Ont.
- Division of Cancer Genomics and Proteomics, Ontario Cancer Institute, Princess Margaret Hospital, Toronto, Ont. M5G 2M9

- Eli Lilly Canada, Scarborough, Ont.
- Faculty of Engineering, University of Regina, Regina, Sask.
- Laboratoire de sciences judiciaires et de médecine légale, Montréal (Que.), H2K 3S7

Thus, in Scopus, firms had to be identified using different algorithms, as follows:

1. Use different filters to retrieve firms in the database. Some terms and abbreviations are highly specific to firms (e.g., Inc, ltd., corp., associates).
2. Search for the names of firms identified in the first step in the database using a shorter form without the specific term. For example, if “Acuren Group Inc.” was retrieved in step 1, then perform a search for “Acuren Group.”
3. Search in Scopus for the names and name variants for each firm listed in Industry Canada firm directories (again, with and without the specific terms, such as inc, corp. and ltd).
4. Filter out terms specific to other types of organizations (e.g., university, hospital, institute). Then manually scan the most common remaining forms of affiliations (not filtered for other types of organizations and not identified in previous steps) to make sure that no important firms have been overlooked.

A similar approach was used to identify firms in the USPTO database. Although simpler, this process required more time than the Scopus exercise because most assignees in the USPTO database are firms.

Despite making a considerable effort to identify firms in the databases, several scientific publications and patents from Canadian firms are missing from the analysis. However, Science-Metrix believes that that it has identified the majority of relevant publications and patents, and that this sample can be used to produce unbiased statistics of IR&D in Canada.

STANDARDIZATION OF FIRM NAMES

Before producing statistics, the name variants for each firm had to be standardized under a single form, and firms listed in both Scopus and the USPTO under one single name. This was another demanding task because each firm in Scopus had to be searched for in the USPTO database, and vice-versa. It has, however, allowed for the additional identification of firms in both databases.

Another challenge was the complexity of the structures and histories of firms. Firms may change names or be bought, merged, or divided. The information on these transformations was not available, and had to be acquired through internet searches. Given the time and resources available for this project, it was not possible to search for information on the status of each firm; thus, some firms

that should be grouped under a single name still fall under two or more forms in the resulting statistics. This should not represent a major limitation to this analysis, particularly at the NAICS level, because the different variants are often classified under the same NAICS code.

MATCHING FIRMS IN SCOPUS AND THE USPTO DATABASE TO A NAICS CODE

The Canadian Company Capabilities (CCC) is a directory of Canadian firms maintained by Industry Canada and available on its website: (Industry Canada, 2013). This database provides the NAICS code for all firms listed (about 55,000). The names and name variants of each firm were downloaded, along with the NAICS code(s). The firms in Scopus and the USPTO database were matched against the CCC using name variants⁶⁸ on both databases. Thus, several firms in Scopus and the USPTO were matched with a NAICS code. Matches with the 1,000 most active firms (using the sum of papers in Scopus and patents in the USPTO database) were validated manually. At this point, 833 firms had a validated match. Then, the NAICS codes for the remaining firms, with a total of five more patents and/or publications were manually searched for on the internet. This was done on a best effort basis.

PRODUCTION OF STATISTICS

Statistics on publications and patents were computed at the industry group level by province and by year for the 2003–2010 period. Statistics were also computed for all firms standardized in Scopus and/or the USPTO database.

PUBLICATIONS

Selection of Database

Access to a database containing the most complete bibliographic information on scientific journals published worldwide is essential for the production of bibliometric data. In this study, the Scopus database (produced by Elsevier) was used to produce statistics on Canadian firms. Scopus currently indexes some 33 million records in more than 18,000 peer-reviewed journals (i.e., articles that are peer reviewed prior to publication), covering nearly every field of science (including natural sciences and engineering, and social sciences and humanities).

68 For Scopus and the USPTO, name variants are the different forms present in the databases, as well as shortened forms, from which some indicative terms (e.g., inc, ltd, corp) have been removed.

Scopus was selected over other databases because it lists the references cited by each document it includes, allowing for internal coverage monitoring of the database and analysis of scientific impact based on citations and impact factors. Also, compared to databases that only provide information on the first author of a publication, Scopus includes all authors and their institutional affiliations.

Number of Publications

This is an analysis of the number of publications obtained using full counting. In the full-counting method, each paper is counted once for each entity listed in the address field and once for each NAICS code associated with the publication. As an example, the following fictive paper is presented with authors and affiliations:

Author	City	Province	Country	Affiliation	Standard-ized name	NAICS
Swindale N.V.	Toronto	Ontario	Canada	Bell Canada Enterprises	BCE Inc.	541510, 517910
Wade G.A.	Ottawa	Ontario	Canada	Cognos Incorporated	IBM Corp.	334110, 334120
Martel R.	Montréal	Quebec	Canada	Bell Business Solutions Inc.	BCE Inc.	541510, 517910
Gelinas P.J.	Montréal	Quebec	Canada	Bell Business Solutions Inc.	BCE Inc.	541510, 517910

- One paper would be counted for each author.
- One paper would be counted for Toronto, Ottawa, and Montréal.
- One paper would be counted for Ontario and one for Quebec.
- One paper would be counted for Canada.
- One paper would be counted for BCE Inc. and one for IBM Corp.
- One paper would be counted for each NAICS code: 334110, 334120, 541510 and 517910.
- One paper would be counted for each industry group (4-digits): 3341, 5415, 5179.
- One paper would be counted for industry group 5415 in Quebec, and one would also be counted for industry group 5415 in Ontario.

Each paper is counted once at any level of aggregation.

Average Relative Citation (ARC)

This indicator measures the scientific impact of papers produced by a given entity (e.g., the world, a country, or an institution) relative to the world average (i.e., the expected number of citations). In this study, the number of citations received by each publication was counted for the year in which it was published and for

the two subsequent years. For papers published in 2003, for example, citations received in the 2003–2005 period were counted. To account for different citation patterns across fields and sub-fields of science (e.g., there are more citations in biomedical research than in mathematics) and across time, each publication's citation count is divided by the average citation count of all publications of the corresponding document type (i.e., a review would be compared to other reviews, whereas an article would be compared to other articles) that were published the same year in the same sub-field to obtain a relative citation count (RC). Since a three-year citation window was used in this study, computation of the ARC score was possible up until 2008. Science-Metrix only computed scores with at least 30 publications. In the case of ARC, at least 30 publications with a valid RC score were needed for computation. Otherwise, the score was not calculated, which is indicated by “n.c.” in tables. If no score was computed because there were no papers at all, the cell was left empty.

The ARC score of a given entity is the average of the RCs of the papers belonging to it. An ARC score above 1.0 means that a given entity is cited more frequently than the world average, while a score below 1.0 means the reverse.

Average Relative Impact Factor (ARIF)

The ARIF is a measure of the expected scientific impact of publications produced by a given entity (e.g., the world or a country), based on the impact factors of the journals in which they were published. The impact factor (IF) of a publication is calculated by ascribing to it the IF of the journal in which it is published for the year in which it is published. Subsequently, to account for different citation patterns across fields and sub-fields of science (e.g., there are more citations in biomedical research than in mathematics), each publication's IF is divided by the average IF of all papers of the corresponding document type (i.e., a review would be compared to other reviews, whereas an article would be compared to other articles) that were published the same year in the same sub-field to obtain a relative impact factor (RIF). In this study, the IF of journals was computed over five years. For example, in 2007 the IF of a journal would be equal to the number of citations to articles published in 2006 (8), 2005 (15), 2004 (9), 2003 (5), and 2002 (13), divided by the number of articles published in 2006 (15), 2005 (23), 2004 (12), 2003 (10), and 2002 (16) (i.e., $IF = \text{numerator [50]} / \text{denominator [76]} = 0.658$). This indicator was computed for the whole 2003–2010 period, as the Scopus database starts in 1996. Science-Metrix only computed scores with at least 30 publications. In the case of the ARIF, at least 30 publications with a valid RIF score were needed for computation. Otherwise, the score was not calculated, which is indicated by “n.c.” in tables. If no score was computed because there were no papers at all, the cell was left empty.

The ARIF score of a given entity is the average of its RIFs (i.e., if an institution has 50 publications, the ARIF is the average of 50 RIFs, one per publication). When the ARIF score is above 1.0, it means that an entity scores better than the world average; when it is below 1.0, it means that, on average, an entity publishes in journals that are not cited as often as the world level.

PATENTS

Selection of Database

The USPTO database is commonly used to measure inventions. Because the United States is the largest market in the world, the most important inventions tend to be patented there, and it is consequently one of the largest registers of patented inventions in the world. Although the USPTO database presents an obvious bias towards the United States, it is still a potent tool for country-level comparisons. In addition, since the focus is on the analysis of Canadian firms, the USPTO database is highly appropriate. Indeed, Canada has more patented inventions for the 2005–2010 period in the U.S. market than in Canada: nearly 18,000 patents in the USPTO database, compared to about 12,000 patents in the Canadian Intellectual Property Office (CIPO) database and about 4,000 patents in the European Patent Office (EPO) database.

Number of Patents (IP)

Unlike scientific publications, patents possess two fields that contain bibliographic information relevant to the geographic origins of a patent: the inventor field and the assignee field. These fields can be used to compute statistics on two different indicators — namely, invention and intellectual property (IP). The majority of patents are owned by corporations, and their addresses, which appear in the assignee field, are used to compute the geographic location of the ownership of IP. For cases in which an individual owns the IP, the address of the owner is used to compute the location of the IP. For the sake of simplicity, this report presents data on IP only. The counting method used is the same as that used for publications: each patent is counted once at any level of aggregation.

Appendix B
Data Challenges in Examining Industrial R&D

Appendix B

Data Challenges in Examining Industrial R&D

This appendix discusses some of the data and methodological challenges that the Panel faced in its examination of the state of industrial R&D (IR&D) in Canada using expenditures on IR&D and patents.

DATA COLLECTION

To estimate how much businesses spend on IR&D, Statistics Canada uses a specialized questionnaire and data from corporate tax returns. The data used by the Panel are for intra-mural R&D (i.e., expenditures on organizations' own R&D). The accuracy of the reported data relies on the accuracy of the data reported by firms and the ability of Statistics Canada surveys to capture all businesses that undertake R&D. Surveys are sent to firms that completed the survey in previous years and received an approved claim for the SR&ED tax credit in prior years, and any other potential performers of IR&D that Statistics Canada can identify. The survey response rate was 75 per cent in 2010.

The Panel was concerned about the accuracy of the reported data. Some firms may be too small to capture, or some firms may be undertaking R&D activities and are either not surveyed or do not realize these activities are considered as R&D. However, data are likely to be reported relatively accurately by firms because of the risk that applications for the Scientific Research & Experimental Development (SR&ED) tax credit would be audited.

CLASSIFICATION METHODOLOGY FOR ALLOCATING R&D EXPENDITURES TO INDUSTRY

Statistical agencies collect data on firm expenditures on R&D and then assign those expenditures to particular industries so that aggregated data can be released and firm-level data can remain confidential.⁶⁹ Enterprises are business units that control their allocation of resources, and for which consolidated financial and balance sheet accounts are maintained. The activity with the most economic

69 Industries are classified using a production-oriented conceptual framework, grouping establishments or enterprises into industries based on the activity in which they are primarily engaged. Those using similar raw material inputs, similar capital equipment, and similar labour are classified in the same industry. Statistics Canada defines an industry as "a generally homogeneous group of economic producing units, primarily engaged in a specific set of activities. An activity is a particular method of combining goods and services inputs, labour and capital to produce one or more goods and/or services (products). In most cases, the activities that define an industry are homogeneous with respect to the production processes used" (Statistics Canada, 2013b).

weight (value added in the case of Canada) within this enterprise determines to which industry that enterprise is classified. In turn, all R&D undertaken by the enterprise is allocated to that industry, conforming to the institutional classification approach of the *Frascati Manual* (OECD, 2002).

In the context of the Panel's analysis, the accepted methodologies created two challenges:

- **Assignment of R&D expenditures to the scientific research and development services industry:** It is difficult to determine for which particular industry or technology resources are being spent in this industry. The industry comprises establishments “primarily engaged in conducting original investigation, undertaken on a systematic basis to gain new knowledge (research), and in the application of research findings or other scientific knowledge for the creation of new or significantly improved products or processes (experimental development)” (Statistics Canada, 2013c). In turn the research and experimental development in this industry can range widely, including research covering electronics, oceanography, pharmacy, biotechnology, psychology, economics, and the humanities. Some countries do not have a scientific research and development services industry into which R&D expenditures can be allocated; instead, these countries reassign R&D carried out by firms in this industry to the industry in which the R&D is being used.
- **Assignment of R&D expenditures to the wholesale trade industry:** The growing complexity of business operations means that many firms selling goods operate without any factories in Canada. Operations in Canada might be made up of marketing operations and R&D activities. Under existing practices, the R&D operations associated with these firms are likely assigned to the wholesale trade industry (or the scientific research and development services industry) rather than to the manufacturing industry normally associated with the product. Indeed, substantial amounts of R&D appear to be undertaken in the wholesale trade industry in Canada.

Although these classification problems do not change the economy-wide level of IR&D undertaken in Canada, they can alter the allocation of this R&D across industries, making assessments of relative expenditures challenging.⁷⁰ Together these two industries, wholesale trade and research and development services, amount to about one-fifth of Canada's IR&D expenditures. Use of the current methodologies has three main implications.

70 Some of these challenges were initially reported by Scherer (1984).

First, R&D undertaken in a manufacturing establishment (and whose other economic activity such as employment would be included in manufacturing) could be allocated to a service industry if that service industry constitutes the majority of the enterprise's activity. This relative weight can change over time, resulting in the firm moving between industry classifications. Statistics Canada suggests that pharmaceutical enterprises can move between i) pharmaceutical and pharmacy supplies in the wholesale and distribution service industry, ii) pharmaceutical and medicine manufacturing, and iii) scientific research and development services. Furthermore, R&D for enterprises related to oil and gas can move from oil and gas extraction to petroleum and coal product manufacturing. (Statistics Canada, 2011).

Second, if a parent company has two subsidiaries, an aerospace firm and a firm producing "other transport equipment", and each has its own balance sheet, R&D for the first firm is presented as taking place in the aerospace industry, and in other transport equipment for the second. However, if financial information is only maintained at the parent corporation, the assignment of R&D to it will fluctuate between aerospace and other transport equipment depending on their economic weights. The industry into which R&D ends up being allocated therefore depends on how a firm decides to organize itself.

Third, the R&D of subsidiaries in Canada of foreign companies mostly involved in the importing and sale of products, but also undertake some R&D, will be assigned to the wholesale trade industry. For Canadian firms, any outsourcing of manufacturing to other countries may lead to their R&D being assigned to wholesale trade.

The magnitude of this issue is unclear, but it is potentially significant given the experience of the United States. Over time, U.S. analysts noted that reported data on R&D expenditures in the wholesale trade industry had been rising whereas the proportions in manufacturing computer equipment and pharmaceuticals had been declining. The method of allocating R&D expenditures had been automated, but closer examination revealed that many U.S. firms in these industries had been outsourcing production to firms outside the country. Consequently, the main operations of the firm remaining in the United States were linked to marketing, advertising, and distribution along with R&D. It was therefore appropriate for the U.S. operations of the firm to be classified by the computer algorithm as wholesale trade even if the main activity of the firm was producing computers or drugs. However, allocating such R&D to wholesale trade rather than computer or pharmaceutical manufacturing would seem inappropriate in providing useful data for analysis.

The correction of this issue in the United States in 2004 led to the doubling of R&D expenditures allocated to the computer and communications equipment industry (Robbins *et al.*, 2007). Methodology revisions meant a 40 per cent increase in the amount of R&D assigned to manufacturing (mostly pharmaceuticals and medicines and information and communication technologies) at the expense of the wholesale trade industry. For 2004, this amounted to a net increase of US\$37.8 billion in R&D reported in manufacturing industries.⁷¹ The National Science Foundation (NSF) has changed its classification algorithms to exclude sales offices of manufacturers. Additional analyst review is applied to R&D allocated to the NAICS management, wholesale trade, and research and development services industries, which may lead to reallocation of R&D previously assigned to these industries (Shackelford, 2007).

It is possible that a similar story is happening in Canada or that subsidiaries of foreign firms that are mostly distributing products in Canada are also undertaking R&D that is then assigned to wholesale trade. These classification challenges likely mean that R&D expenditures in wholesale trade in Canada are probably capturing R&D expenditures associated with pharmaceuticals and electronic equipment. Departing from current classification practices will be difficult because data reported by industry in Canada need to conform to the Canadian System of National Accounts. Linking IR&D expenditures with the North American Product Classification System (NAPCS), however, would resolve many of the problems that make interpretation of the data challenging.

Other countries try to lessen the classification problem by providing information on a functional distribution (also allowed for by the *Frascati Manual*) rather than the institutional classification followed by Canada, and assign R&D expenditures in one of the following ways:

- **Directly according to product field:** e.g., Finland, Sweden, United Kingdom.
- **Through adjusted product field:** e.g., Japan, Norway, Spain. For example, government analysts moved R&D between industries in Japan since Japanese firms usually have a broad conglomerate structure.
- **Reallocating R&D services to the industry served:** Grablowitz *et al.* (2007) reported that France does not have an “R&D services” industry as any such service is allocated to the industry that requested the service. Duchêne *et al.* (2010) reported that the United Kingdom, Germany, Belgium, Finland, and Denmark at least partially reallocate BERD from R&D services to those manufacturing industries for which the R&D was conducted.

71 Total IR&D expenditures in the United States in 2004 were US\$208 billion (NSF, 2008).

According to OECD (2013), Belgium, the Czech Republic, and South Africa provided data according to both classification approaches. The OECD states that its *Analytical BERD (ANBERD) Database* is based on the functional distribution approach where possible.

Interpreting Trends

Interpretation of long-term trends is difficult because there are often many reasons that could explain them. For example, several potential explanations exist for the rapid rise in patenting over the last two decades, as discussed in Box B.1. Analyzing trends could be made easier if a consistent way was used to deflate R&D expenditures so as to obtain an index of the quantity of R&D. Nominal R&D expenditures are only reported currently so that, for example, growth in expenditures may indicate that more people are being hired (which may be a sign of more research activity) or that only salaries of R&D workers are increasing (so research activity may be unchanged). However, devising effective means of deflating BERD is challenging (Copeland & Fixler, 2012; Copeland *et al.*, 2007, and Annex 9 of the *Frascati Manual* (OECD, 2002)). Statistics Canada has begun to capitalize R&D for inclusion in the National Accounts as of 2012. Consequently, future analysis will look at methods to introduce depreciation of this stock.

Lags in Producing Data

Data on IR&D needs to be put in context by international comparisons and by comparing to the nominal value added and/or sales of an industry. The most recent data for expenditures on R&D by industry for Canada from the OECD's ANBERD database are several years old. Given rapid changes in some industries, untimely data make it challenging to identify areas of current strength. Significant lags in producing data on nominal value added in Canada make it difficult to evaluate the impact of the recent recession and corporate restructuring on IR&D since calculating IR&D intensity is not as accurate with real or constant price data.

Missing Data on Provinces

To protect confidentiality, Statistics Canada often limits data release at the detailed industry level, which can make assessing IR&D strengths in smaller provinces challenging. Although patent data are available at a more detailed level, the lower number of citations makes it difficult to draw inferences on relative strengths in niche areas.

International Comparability

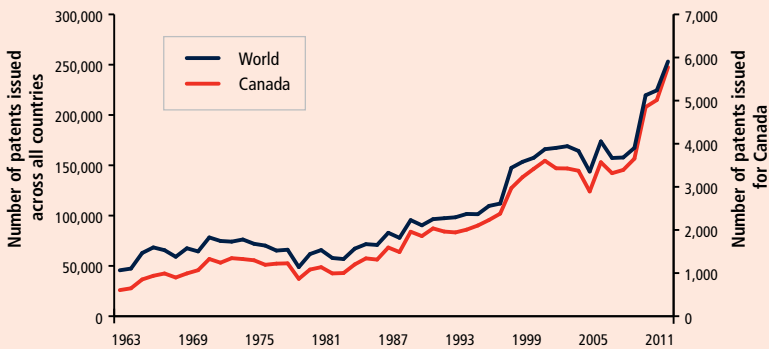
The OECD has led efforts to harmonize measurement of BERD through encouraging consistent methodologies. Its guidance is laid out in the *Frascati Manual* (OECD, 2002). In practice, data gathering methods and interpretations

Box B.1

Interpreting the Trend in Increased Patenting

The reasons for the sharp rise in the number of patents granted over the last three decades are difficult to interpret. The Figure below shows that the number of patents granted by the U.S. Patent and Trademark Office has grown by a factor of five since the early 1980s. Canadian patent counts have tightly tracked trends in global production (right scale). Since the early 1990s, Canada has consistently produced around 2 per cent of the world's patents, up from the early 1960s when Canada only accounted for 1.3 per cent of patents issued. Looking at trends in patenting as a sign of strength in an industry may therefore be misleading if the rise in patents is not related to the underlying cause of this change.

Several reasons have been put forward to explain why there is more patenting: the pace of technological change may have quickened; the costs of patenting may be lower; business strategies may have changed from increased economic importance of non-material products, or from rising legal costs of violating patent laws; or there may be increased reliance on patents rather than industrial secrecy to retain hold of information if workers have become more mobile between firms (Hall & Ziedonis, 2001; Shapiro, 2001). Griliches (1990) discussed how trends in patenting slowed down in the late 1970s in the United States because of insufficient budget for the U.S. Patent and Trademark Office: there were not enough patent examiners to validate patent applications. The evolution of these factors makes it more difficult to compare the levels of patenting over time to determine where Canada's strengths lie. As a result, the Panel looked at trends within particular industries in Canada compared to other countries.



Data source: USPTO (2012)

Patents Granted for Canada and the World

of definitions limit true comparability: sampling methodologies for small firms may differ and research institutions with a mix of private and public funds may not be classified in the same way, for example. The *Frascati Manual* notes that the greatest source of error is “the difficulty of locating the cut-off point between experimental development and the related activities required to realize an innovation” (OECD, 2002).

Comparing the levels of expenditures on R&D across countries is inappropriate since the cost per unit of R&D varies because of differences in the wage costs of researchers, for example. This problem can be mitigated by looking at R&D intensities (R&D divided by GDP).

A concern in comparing patenting rates across countries is that the costs and ability to patent vary across countries (Kortum and Lerner, 1998). Until the 1970s, the proportion of patents granted in France was nearly three times the proportion in Germany, for example (Griliches, 1990). This effect is partly mitigated by only looking at data from the USPTO (as the Panel did for this assessment), but firms may still have different propensities to patent across countries.

Technology versus Economic Classifications

Popular discussion of technologically advanced industries does not match the economic classification of industries according to, for example, the NAICS. Biotechnology refers to the use of biological systems in the manufacture of different products, but there is no “biotechnology” industry. Instead, the methods of biotechnology are adopted in industries as diverse as pharmaceuticals and waste management.⁷² For biotechnology in the United States, Battelle/Bio (2012) constructed a definition of the bioscience industry from 27 detailed NAICS industries (at the six-digit level).⁷³ The OECD has also endeavoured to classify patents according to better-understood technological fields.

A bigger challenge is that the data on economic variables such as R&D expenditures are allocated to economic industries, such as pharmaceutical or computer manufacturing, whereas technology-based data (e.g., on patents) are allocated to technologies, such as drugs or semiconductors. Some technologies and industries can be lined up (e.g., semiconductor technology is likely to be used in the computer

72 In the United States, biotechnology research is captured under NAICS 541711: “Research and Development in Biotechnology.” Statistics Canada surveys ask firms to identify the field of science or technology in which R&D was performed, including environmental and industrial biotechnology.

73 De Avillez (2011) provides an estimate of the size of the biotech industry in Canada, noting that Statistics Canada stopped producing estimates of its size in 2005.

and electronics equipment industry), but others cannot. The classic example of this problem was the growing proportion of patents in the Japanese aerospace industry in the 1970s that turned out to be a misclassification of engine patents developed for the motor vehicle industry (Griliches, 1990).

The main method of aligning technology and economic classifications is through the company names to which many — but not all — patents have been assigned. This process is fraught with problems. Assigning a company name like Novartis to pharmaceuticals may be relatively straightforward, but it is less clear to which industry a firm like IBM (which operates in multiple industries) should be allocated. Furthermore, since there is no well-defined classification of company names, business names may be entered inconsistently (e.g., RIM or Research in Motion) or may be replaced through mergers and takeovers, which Trajtenberg *et al.* (2006) call the “who is who” problem. The problem also applies to those who invented the patent: the “John Smith” problem where individuals with the exact same name may be different inventors. Trajtenberg *et al.* (2006) argue that only computer algorithms can solve these problems given that with over two million patents with an average two inventors per patent, there are four million records to be sorted out.

A further challenge in aligning data is that since many patents are assigned to individuals (e.g., an academic), there is no clear way of aligning a patent to an industry. If these individuals subsequently start their own companies, the economic classifications will correctly allocate subsequent R&D expenditures; however, it will remain difficult to assign the patent data to the right industry.

Without consistent firm-level identifiers that match other databases, researchers need to rely on firm names to combine datasets (as was done by Science-Metrix for the analysis carried out for the Panel). Original analysts such as Schmookler (1966) had to manually align firm names, but there are now thousands of patents making such a process unwieldy. Efforts are now underway to attempt to automate this process. Silverman (1999) developed a methodology to link patents issued in Canada to the Standard Industrial Classification (SIC) classification (a precursor of NAICS), but this was a one-off exercise. Thoma *et al.* (2010) and Schmoch *et al.* (2003) have made further progress on computational methods, but it is unclear if a satisfactory solution can be found until better classification methodologies are adopted by the various government agencies involved, including linking patent applicants to business numbers.

Assessments of the Council of Canadian Academies

The assessment reports listed below are accessible through the Council's website (www.scienceadvice.ca):

- The State of Industrial R&D in Canada (2013)
- Innovation Impacts: Measurement and Assessment (2013)
- Water and Agriculture in Canada: Towards Sustainable Management of Water Resources (2013)
- Strengthening Canada's Research Capacity: The Gender Dimension (2012)
- The State of Science and Technology in Canada (2012)
- Informing Research Choices: Indicators and Judgment (2012)
- Integrating Emerging Technologies into Chemical Safety Assessment (2012)
- Healthy Animals, Healthy Canada (2011)
- Canadian Taxonomy: Exploring Biodiversity, Creating Opportunity (2010)
- Honesty, Accountability and Trust: Fostering Research Integrity in Canada (2010)
- Better Research for Better Business (2009)
- The Sustainable Management of Groundwater in Canada (2009)
- Innovation and Business Strategy: Why Canada Falls Short (2009)
- Vision for the Canadian Arctic Research Initiative: Assessing the Opportunities (2008)
- Energy from Gas Hydrates: Assessing the Opportunities and Challenges for Canada (2008)
- Small is Different: A Science Perspective on the Regulatory Challenges of the Nanoscale (2008)
- Influenza and the Role of Personal Protective Respiratory Equipment: An Assessment of the Evidence (2007)
- The State of Science and Technology in Canada (2006)

The assessments listed below are in the process of expert panel deliberation:

- Canadian Industry's Competitiveness in Terms of Energy Use
- Canadian Ocean Science
- Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction
- Medical and Physiological Impacts of Conducted Energy Weapons
- Memory Institutions and the Digital Revolution
- The Future of Canadian Policing Models
- The Potential for New and Innovative Uses of Information and Communication Technologies (ICTs) for Greening Canada
- The State of Canada's Science Culture
- The State of Knowledge of Food Security in Northern Canada
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