Science, Technology and Innovation Indicators in a Changing World

RESPONDING TO POLICY NEEDS

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Science, Technology and Innovation Indicators in a Changing World

Responding to Policy Needs

OECD

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 30 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

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Foreword

This volume is a synthesis of the thinking coming out of the second OECD Blue Sky Forum on new indicators for Science, Technology and Innovation (STI) and proposals for work over the next few years. The forum, held in Ottawa on September 25-27, 2006 attracted 250 people from 25 countries. Over 50 papers were presented, followed by productive discussions.

For this volume, a selection of papers was revised by the authors, and some were combined, to present the key outcomes of the forum in a manner that made them as accessible as possible to a broader community than that of the day to day producers and users of STI indicators. As the world interconnects, the pervasive nature of science, technology and innovation activities are potentially part of every policy and every policy and regulation has some impact on science technology and innovation. Making the findings of the Blue Sky Forum as widely accessible as possible extends the public policy discourse and emphasizes the importance of STI indicators in that debate.

As well as making the findings of the Blue Sky Forum widely available, the volume raises issues that will form part of the work plan for STI indicator development and they will also influence OECD outreach activities. A fact of indicator development in the 21st century is that the OECD is not alone in doing it, and it is imperative to work with the other organizations that are demonstrating competence in the subject so that the collective work is more than the sum of its parts.

The second Blue Sky Forum in Ottawa followed ten years after the first one in Paris in 1996. With the rate of technological and organizational change going on in world, the next Blue Sky Forum may have to be sooner than a decade away. However, this book sets the course and poses the questions that have to be addressed as the STI indicator community, both producers and users, moves forward.

The OECD Blue Sky Forum would not have been possible without the support of the host agencies in Ottawa, Industry Canada and Statistics Canada, and the involvement of the U.S. National Science Foundation under grant SRS-0544653.

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This publication would not have been possible without the funding of the Canadian Federal Policy Research Initiative, and it would have been less readable without the tireless style and content editing of Jennifer Wilson and the cooperation of the authors. Many people helped produce this volume, including Carol Blais-Blake from Statistics Canada and Joseph Loux from the OECD. Anthony Arundel, Alessandra Colecchia and Fred Gault served as editors. Choosing among many valuable contributions was a hard and subjective task. All of the original versions of the papers, as well as those not included in this volume, can be viewed and downloaded from the OECD web site at: *www.oecd.org/sti/blueskyconference*.

This volume contains a paper co-authored by Professor Christopher Freeman, the same Christopher Freeman who, 45 years ago, drafted the first version of what would become the *Frascati Manual* and which gave rise to the Frascati family of manuals that support work on a wide range of science, technology and innovation indicators. The manuals, and the methods, stimulated much of the debate held at the Blue Sky II Forum. This volume is dedicated to Christopher Freeman in recognition of his contribution to our subject.

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Chapter 1

SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS: THE CONTEXT OF CHANGE

Fred Gault
Statistics Canada

1.1. Introduction

The second OECD Blue Sky Forum took place in Ottawa in September 2006 to examine science, technology and innovation (STI) indicators for use in policy in the 21st century. The context for indicator development, and use, had changed considerably from the first Blue Sky Forum in Paris in June 1996 and this book looks at those changes and how they are influencing indicator development.

1.1.1. A decade of change

It is an appropriate time to look back, and to the future, as 2007 is the 50th anniversary of the first OECD expert group dealing with science and technology indicators (OECD 2002: 151) and it occurs at a time when the OECD is considering expanding its membership and when other international organizations are looking at the role of STI indicators in their policies. If there is a word that summarizes what is going on in 2007 as this book is being written, it is 'interconnected' and the interconnection of various indicators, policies and programmes is a recurring theme in the book.

In the early days of indicator development at the OECD, the focus was on indicators related to research and development (OECD 1963), but the last 20 years have seen work on innovation, intellectual property, technological balance of payments and S&T personnel. While this has been going on, the Berlin wall fell, opening up Central and Eastern Europe, and Brazil, Russia, India and China, the BRICs, have emerged as economic powers. These changes have been chronicled by Thomas Friedman (2006) in his book, *The World is Flat*, and the OECD has contributed a handbook on indicators for globalization (OECD 2005a).

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When experts gathered for the 1996 Blue Sky Forum, crude oil was below $20 a barrel, compared with more than $60 in 2006 and 2007 when it reached $70. The Internet was in place, but the impacts of the Web and e-commerce were yet to be felt. Wireless telephones existed but had yet to include broadband and the powerful computer applications of 2007 and the impacts of biotechnology were not as pervasive as they are now. Analysts were aware of the aging population in most of the industrialized countries but the concern about the loss of knowledge through retirement, the cost of healthcare and the impact on social programmes were not as high. Climate change, biodiversity and availability of water, were emerging issues.

What came out of the first Blue Sky Forum were discussions and papers on knowledge, intellectual property protection, innovation, and on government programmes of direct and indirect and indirect support for technology and R&D (OECD 2001). As well, there was discussion of the need to take a systems approach to the development of indicators.

The intellectual property discussion let to the OECD work on the triadic families of patents and on-going analysis (OECD 2006a, 149), the knowledge discussion resulted in new indicators used by the OECD in its publications (OECD 2005b), as well paving the way for work on measuring knowledge management (OECD 2003). Work on innovation continued and contributed to the 2nd and 3rd editions of the *Oslo Manual* (OECD/Eurostat 1997; OECD/Eurostat 2005). Tax treatment of R&D is still a current topic at OECD as more countries adopt various forms of tax incentives. The 1996 discussions of a systems approach to STI indicators inspired work in member countries (Statistics Canada 1998) which is still going on.

As the decade progressed, the need to continue to take a systematic look at indicator development became more widespread. In 2004, the China Society for Science and Technology Indicators met to review the need for indicator development. The OECD Global Science Forum brought indicator and policy experts together in Finland in July 2006. The 32nd Seminar of the European Advisory Committee on Statistical Information in the Economic and Social Spheres (CEIES) discussed 'Innovation Indicators – More than Technology' in February 2007 and the *Red Iberoamericana de Indicadores de Ciencia y Tecnologia* (RICYT) met in May in Brazil in 2007 to consider new science and technology indicators.

More broadly, the OECD held its second OECD World Forum on Statistics, Knowledge and Policy in Istanbul in June 2007, which covered, among other topics, climate change, biodiversity, knowledge, human capital, demographic issues and technology. In Europe, the European Union's Seventh Framework Programme (Muldur *et al.* 2006), while not explicitly focused on STI indicators, does cover a wide range of interconnected

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research topics that will require complex indicators for monitoring and evaluation. The same could be said for the UN Millennium Development Goals (MDGs).

In September 2007, the African Union is convening its first Intergovernmental Committee on African Science, Technology and Innovation Indicators in Mozambique and the Russian Federation, with the European Commission and the Italian statistical office, is holding an international indicators meeting in Moscow in November 2007.

The meeting in Ottawa in 2006 was part of this global interest in the intersection of indicators and policy. The 2006 forum was different from that of 1996, both in content and in its collective sense of urgency to produce indicators needed to address the issues of the day and to support evidence-based policy development. It recognized the interconnection of indicators and the need to address multiple issues, as well as individual ones. Luc Soete and Chris Freeman in Chapter 15 note that what was important in 20th century development of STI indicators may not be as important in the 21st century, but the information may now be misleading when not connected to the activities of other actors in the economic and social system. This point is also made by John Marburger in Chapter 2 who observes that ‘in the face of rapid change, old correlations do not have predictive value’. It is the need to understand the dynamics of change that drives the development of STI indicators in the 21st century.

1.1.2. Evolution of indicators

STI indicators, their development, interpretation and use, are the province of the OECD Working Party of National Experts on Science and Technology Indicators (NESTI) which reports to the Committee on Scientific and Technological Policy (CSTP). NESTI has been in place for over 40 years and its roots in the organization go back half a century. It systematically reviews the need for indicators, encourages experiments in their production and use, and codifies the knowledge in the form of manuals. Then, it manages the revision of the manuals.

The manuals allow the ‘routines’ of data collection, interpretation and indicator development to be shared by thirty member countries and by non-member countries that wish to produce indicators that can be compared internationally. This is not a static process as the economy and the society change, as they have done significantly over the last decade, and the manuals are revised in light of the experience. Two examples are the emphasis on R&D in service industries in the 6th edition of the *Frascati Manual* (OECD 2002) and the addition of a chapter on linkages in the 3rd edition of the *Oslo Manual* (OECD/Eurostat 2005) that deals with innova-

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tion. The manuals, the tacit knowledge held by the experts, and the formal language used to discuss the measurement and interpretation issues are equivalent to a technology and, like machine-based technologies, they do not always behave, or diffuse, as expected.

Richard Nelson (2003) has made the point that it is ‘more difficult for a technology to advance if learning is limited to what can be acquired by doing or using’ and that does raise a question about how indicators, and their use, advance the understanding of the subject, and whether there is a science underlying the evolution that helps with the advance. Over the last decade, there have been examples of transferring the practices of NESTI to other groups, some more successful than others.

By 1996, NESTI had produced manuals on R&D (OECD 1994a), patents (OECD 1994b), technological balance of payments (OECD 1990), innovation (OECD 1992) and S&T personnel (OECD/Eurostat 1995). All of these had come out of the same process of experiment, comparison of country experience, and consensus on best practice. However, in 1996 the OECD Committee on Information, Computer and Communications Policy (ICCP) recognized the need for statistical support and indicator development describing the information society. The subject matter was quite removed from that involved in knowledge creation, protection, transmission and delivery to the market so a new ad hoc panel was established in 1997 to develop indicators for the information society, chaired initially by a Vice-Chair of NESTI to maintain the network and to transfer the working practices. The ad hoc panel became the Working Party for Indicators of the Information Society (WPIIS) in 1999 and now has an agenda at least as full and complex as that of NESTI and produces its own guidelines for indicator development (OECD 2005c).

In 2000, the need for comparable statistics on biotechnology was recognized by both NESTI and the Working Party on Biotechnology (WPB) and an ad hoc group was established which was managed by NESTI and informed the agendas of the two Working Parties. By 2004, it had achieved its initial objectives of developing definitions for statistical purposes, models surveys for data collection, and the collection and dissemination of statistics and indicators (OECD 2006b). After a period of working virtually, it has been reconstituted to serve WPB.

In 2007, with the creation by CSTP of a Working Party on Nanotechnology, once again an ad hoc group of experts has been established to follow the same programme as in biotechnology. What this demonstrates is that the practices are transferable and help the subject to advance. A consequence is that NESTI has had to become a broker and co-ordinator, as well as a subject matter committee.

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These examples illustrate the ability to transfer the practices of NESTI into different groups dealing with different subjects, but they do not address the question of the underlying science that could support experiments and advance the development of indicators. John Marburger does look at this question in Chapter 2 when he introduces the science of science policy.

It is, perhaps, worth noting one case where an indicators programme, similar to those just described, did not result from several years of work and that is the case of indicators of knowledge management. The decision to undertake the work grew out of an OECD forum held in Ottawa in 2000, managed by the OECD Centre for Education, Research and Innovation (CERI), and followed by meetings in Denmark, Germany and Paris. The meetings and the work of participants produced a model survey and descriptions of attempts to measure knowledge management in participating countries. The final outcome was an OECD book (OECD 2003), but there was no ad hoc group or established working party ready to take on this subject. Dominique Foray discusses this further in Chapter 6, but the real outcome was the inclusion of knowledge management issues in the 3rd edition of the *Oslo Manual* (OECD/Eurostat 2005).

A final example is the work on human resources for science and technology (HRST), discussed in Chapter 11. The work has been done within NESTI, but the subject is complex and involves issues of education and training, labour force participation, mobility and life-long learning. The question naturally arises as to whether this work would be better supported by a link with other working parties, much as the work on biotechnology has benefited from its connection with WPB.

1.1.3. A systems approach

The use of a systems approach to indicator development and classification has been growing over the last decade as a way of getting at the dynamics of change. The starting point for the approach is the actor, or the economic agent, such as a firm, a public institution, or an individual. Actors engage in activities and some examples of STI activities are R&D, invention, innovation, diffusion of practices or technologies, and human resource development related to all of these activities. Actors, engaged in activities in the system are linked to other actors and activities. Some examples of linkages are contracts and co-operation agreements, co-publishing, commercialization of intellectual property, and flows of knowledge and capacities through the movement of people. As a result of activities and linkages, there are short term outcomes, such as increased sales, productivity or market share leading, over time to economic and social impacts. The changes in social behaviour, and in industrial organization and practices resulting from wireless communication are examples of impacts.

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Understanding the system requires more than aggregate statistics produced at regular time intervals. The micro-data relating to the actors have to be available for analysis and the analysis is improved if different data sets can be linked together to provide more information. Of course, this presupposes that organizations bound by confidentiality agreements, such as statistical offices, are able to provide the access while protecting confidentiality. Following the behaviour of actors over time supports the study of causal relationships, rather than correlations of characteristics from aggregate cross-sectional data. However, to asses impacts, a variety of techniques are needed, including case studies, as there is rarely a clear path from a technological and organization change and economic and social impacts.

While a systems approach is not new in economic analysis (Simon 1996), the contributions to this book demonstrate that it is now being seen in the development of STI indicators.

1.2. Policy: development and application

Indicators are developed to be used and the policy community is the target. However, for this to work, there has to be a dialogue between the two communities about the availability of data, information and knowledge that can be used and about what needs to be developed.

If the dynamics of the system are to be understood, there have to be micro-economic models that can be used to simulate social behaviors and which include boundary conditions, such as the availability of energy, materials or highly qualified people, which constrain the process. Such models could provide scenarios as a basis for the dialogue between the policy and the indicator community as well as input to the more conventional macro-economic models.

The need for micro-economic models is raised by Marburger in Chapter 2 as part of building a new social science discipline, the science of science policy, which could take advantage of econometric methods and model building to provide the science policy makers with the same support now provided by the system of national accounts and econometric research to the makers of fiscal and monetary policy. The U.S. National Science Foundation has moved to support the development of a science of science and innovation policy (SciSIP) by inviting applications for grants in this area (NSF 2007).

The system of national accounts (SNA) has been in place much longer than the current set of STI indicators and it is a system, something STI indicator developers are still working towards. However, the two activities

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are now overlapping after a decision by the UN Statistical Commission in February 2007 to treat R&D expenditure as capital expenditure in the next revision of the SNA. This means that a broader community of users will be involved with R&D data and with the economic and social implications of their change.

Reinhilde Veugelers, in Chapter 3, looks at the link between STI indicators and evidence-based policy in the European Union and makes reference to the Barcelona target of 3% of Gross Domestic Product to be spent on R&D in the EU, initially by 2010. This raises a question of language and interpretation as the target is reported in EU documents as 3% of GDP allocated to R&D, but in the Presidency Conclusions of the Barcelona European Council (2002) the relevant paragraph is the following.

> Paragraph 47. In order to close the gap between the EU and its major competitors, there must be a significant boost of the overall R&D and innovation effort in the Union, with a particular emphasis on frontier technologies. The European Council therefore agrees that overall spending on R&D and innovation in the Union should be increased with the aim of approaching 3% of GDP by 2010.Two-thirds of this new investment should come from the private sector (European Council 2002).

The expenditure is to be on ‘R&D and innovation’ not just on R&D and this is a significant distinction from the perspective of allocating the two-thirds of resources from the private sector. More firms engage in the activity of innovation than in R&D suggesting that the 3% target would have been more accessible had it been interpreted in the way it was originally presented, including both R&D and innovation.

Veugelers goes on to develop the indictor requirements for the European Union and raises the need for a systems approach and for micro-level data and analysis. The systems approach includes the need for linkage measures to help explain the ‘European Paradox’ (Soete 2006), the apparent inability for the knowledge in the well supported public science system to translate into commercial value.

Both Chapters 2 and 3 present the policy need not just for more indicators, but for indicators which are linked together so that they can tell the story about change in the system. They both stress the need for micro-economic analysis and the implicit requirement for access to micro data if the analysis is to be done.

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1.3. New and better measures

Innovation, which connects to the market, has been a subject for policy and indicator development for more than twenty years and the subject continues to evolve. Anthony Arundel, in Chapter 4, observes that innovation policy in Europe is heavily focused on those firms that do R&D but, as noted above, more firms innovate than perform R&D. If the policy objective is wealth creation, it is important to understand the innovators that do not do R&D. A striking observation is that 41% of innovative firms in the Community Innovation Survey (CIS) data being studied innovate by adopting technology from other organizations. This leads to a question of how that adoption took place (Arundel and Sonntag 1999) and the role of user initiated innovation (von Hippel, see Chapter 8).

Arundel also observes that international comparisons do not always work, even if the relevant manual is followed. He examines some of these problems in Chapter 4 and finds that there are cultural differences in countries that give rise to different interpretation of the same question. This is one of the reasons for doing cognitive testing of survey questions in the language that they are to be administered in, in the region of the respondent. To address the situation, he introduces composite indicators that give more credible international comparisons.

While Arundel makes the case for getting more policy-relevant information out of the CIS data, Tara Vinordrai, Meric Gertler and Ray Lambert in Chapter 5 introduce the importance of the concept of design in the process of innovation. This touches on the importance for industrialized economies to move up the value chain by using the creativity of their labour forces to produce more desirable and usable goods and services. It also establishes the need for new indicators related to the process of innovation, but that also is a call for the engagement of the policy community in this important area.

Dominique Foray, in Chapter 6, argues the case for indicators related to knowledge, and specifically for knowledge management, following the OECD pilot project (OECD 2003) which established proof that such information could be gathered and compared. The chapter shows the difficulty of developing a new class of indicators even when it may seem a reasonable thing to do and the pilot project never yielded an OECD manual or handbook. However, the work on knowledge flows and knowledge management was not lost. As Foray points out, it appears, somewhat transformed, in the 3rd edition of the *Oslo Manual* (OECD/Eurostat 2005), as part of industrial organization and practice. As with non-R&D performing innovators, use of design and a creative labour force, the developing of

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indicators of knowledge practices needs dialogue with the policy community to make the case, and this takes time.

The final chapter in the section, Chapter 7 by Heidi Ertl and colleagues, moves along the innovation chain and proposes indicators of impacts of activities linked to innovation. This includes the importance of commercialization indicators which deal with what has to be done to make the product, once delivered to the market, successful. This enhances the information about innovation which just deals with putting a new product on the market or finding better ways of producing or delivering it.

Chapter 7 covers indicators for a number of technologies and makes points raised by others such as the need to use micro-data, to do longitudinal analysis, to link data sets to enhance their value for analysis, to use a variety of methods for indicator development and insight, such as case studies, as well as aggregate statistics and micro-economic simulation modeling, and the importance of understanding the behaviour of the firm over time to study the dynamics of survival and growth characteristics.

1.4. Actors and linkages

Technological and related organizational change activities are initiated by actors which could be firms, public institutions or people. The actors are tied together by linkages in the economy and the society and these linkages raise questions and offer opportunities for a better understanding of the dynamics of the system.

Eric Von Hippel, in Chapter 8, looks at the role of the user in the innovation process and poses some challenging questions about intellectual property protection and about how innovations are transferred from the innovative use to others in the community of practice or back to the suppliers of the original product. This leads to discussion of an ‘information commons’, open source software, and methods of free revealing.

One of the questions coming out of this work is whether intellectual property protection instruments are achieving the intended purpose of disclosure in return for a temporary monopoly or whether they are being used strategically by firms to inhibit other firms from gaining the economic benefits of invention and innovation. A second question is whether the current intellectual property regime is appropriate for a world where more and more users of goods and services are able to change them to their advantage and may then wish to share these changes with others.

The use of intellectual property and its protection form part of the business strategy of the firm, for those firms with the capacity to develop and manage a business strategy. With the 3rd edition of the *Oslo Manual*

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(OECD/Eurostat 2005), attention is turning more to the organization of the firm, including the use of business practices and strategies, as well as the development of new or existing markets for the goods or services produced. Developing STI indicators of business practices or strategies is a relatively new activity and it carries with it the question of how successful these activities have been.

Richard Fabling, in Chapter 9, presents evidence from surveys in New Zealand which shows that management practices, as well as innovation, can be measured and related to outcomes. This introduces the concept of a panel survey to the discussion and the importance of making the same set of observations of the same firm over time. Such longitudinal analysis provides an opportunity to see the effects over time of changes in the practices of the firm or in the environment in which it operates.

Institutions can be observed at different points in time and they can also be observed as they interact with other institutions. Richard Hawkins, Cooper Langford and Kiranpal Sidhu, in Chapter 10, examine the role of the university in an 'innovation society' and how it transfers knowledge to the private sector. This leads to an exploration of knowledge pathways and a call for statistical measurement of the transfers, an issue that appears later in Chapter 13.

The chapter by Laudeline Auriol deals with highly qualified people as stores of knowledge and as vectors of knowledge flow. The specific interest is in the international mobility of doctorate holders and the chapter demonstrates that measuring mobility is not easy, but it is important if there is to be better understanding of temporary mobility, such as the taking of a post-doctoral fellowship for a few years and returning home, and 'brain drain' which may involve migration and the taking of a permanent position. In Chapter 11 she stresses the importance of collecting information on the intentions of doctorate holders and on the motivation for their mobility. The indicator development that follows from Chapter 11 is essential for the understanding of the dynamics of the STI system.

The role of doctorate holders in the STI system is part of a larger question which related to the education and training and mobility of the labour force. The European Commission (2007) has proposed a coherent framework of indicators and benchmarks for monitoring progress towards the Lisbon objectives in education and training. Eurostat reports on the mobility of human resources in science and technology (Meri 2007) and the U.S. National Science Foundation reports every two years on the science and engineering labour force and its education (National Science Board 2006).

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1.5. Connections and impacts

The interest in indicator development in the 21st century is moving from indicators of activities and linkages to indicators of outcomes in the short term and longer term impacts. Chapters 12 to 14 deal with outcomes and impacts from three different perspectives: biotechnology; the funding of health research; and, sustainable development. Impacts in these and other areas are sure to be on the agenda of the next OECD Blue Sky Forum.

Antoine Rose and Chuck McNiven, in Chapter 12, tackle the need to establish impact measures of biotechnology as it grows in importance, much as the generic information and communication technologies (ICTs) have done. This draws upon work of the ad hoc group on biotechnology at the OECD (OECD 2006b) and points the way to development of the agenda of that group as it starts to meet again.

Alan Bernstein, and colleagues, in Chapter 13, look at how the impact of the funding of health research can be measured and a framework and a process, which is still being developed is presented. Given the demands on government funding the question of what the government gets for funding health research, or any other research, cannot be avoided. The development of the framework and its application by the Canadian Institutes of Health Research provides a laboratory for others trying to do the same in support of evidence-based choice on the part of government, followed by ex-post justification based on impact analysis. As an example, the importance of such evidence for evaluation is raised by Sarewitz (2007) in relation to the doubling of the budget of the U.S. National Institutes of Health (NIH).

Michael Bordt, Julio Rosa and Johanne Boivin open up the issue of STI and sustainable development and make some proposals for how to integrate the two. This was also the subject of a conference sponsored jointly by the OECD and the government of the Republic of South Africa in 2005 (OECD 2007), the outcome of which is still influencing OECD agendas.

Dealing with sustainable development is both important and timely as the linkages in the economic system become more evident. Concern about climate change, energy costs and security have led to the use of food crops for the production of bio-ethanol which is intended to reduce the dependence on fossil fuel. As result, the growing demand for bio-fuel is underpinning higher agriculture prices (OECD-FAO 2007). The impact of this goes beyond the increasing cost of popcorn in cinemas. When combined with increased food demand from China and India, and the cost of energy needed for transport, the UN World Food Programme now needs more money to feed the hungry. To deal with this requires many technologies, practices and policies to work together and to reinforce one another to

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achieve a common objective. Providing the STI indicators to inform this work is a major and important challenge.

1.6. What have we learned and where are we going?

Christopher Freeman and Luc Soete bring the book to a close by warning the indicator and the policy communities about using 20th century thinking in the 21st and they broaden the debate to include developing as well as developed countries, which is essential in an interconnected and interdependent world. A shift is suggested from the importance of the formal creation of knowledge to the combination of existing knowledge to make new knowledge that can be used to create value. However, this raises questions, already discussed, about the functioning of intellectual property policy in the 21st century.

Along with other contributors to the book, they stress the importance of organizational and cultural factors in relation to technological impact in a development context which gets back to the need to understand the framework conditions within which development takes place and opportunities for sustainable growth appear.

In the final chapter, Alessandra Colecchia presents what the OECD and its committees could aim to do in the short and medium term. This will determine the outcomes and the longer term impacts of the second Blue Sky Forum and set the stage for the third.

1.7. Conclusion

In summary, the 2006 OECD Blue Sky Forum, and the contributions to this book, make the point that STI indicators, whether new or established, are needed to tell the story of economic and social change. To do this, their emphasis must shift from activity measures to impact measures to observe the consequences of activities, such as innovation, and to support the monitoring and comparison of policy interventions. However, this does not mean that measures of activities and linkages should be forgotten.

Making this happen requires co-ordination, focus and synthesis within organizations like the OECD, and across international and supranational organizations. For the analysis to address the issues of the 21st century, there has to be access to the micro-data on individual actors in the STI system, so long as the confidentiality of the respondents is protected.

Developing a science of science policy as a social science discipline paves the way for a theoretical underpinning for STI indicator development,

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which will allow this ‘social technology’ to advance more quickly and effectively.

Within the subject of STI indicator development, human resource measures require attention before the next Blue Sky Forum as it is the highly qualified people that create, transmit and use knowledge to create value.

In a global economy that links together the developed and the developing countries, understanding the role of STI in sustainable development is a challenge for the next decade.

Not to be forgotten are classifications and guidelines that are needed to collect and interpret data on the STI system and to produce indicators that can be compared over time, across geography and national boundaries. This is the work that expert groups like NESTI have been doing for half a century.

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Part Two

POLICY PERSPECTIVES

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Chapter 2

THE SCIENCE OF SCIENCE AND INNOVATION POLICY

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Policy *making*, while not simple, can be pursued in a straightforward way, with traditional phases of data gathering and analysis. Policy *implementation* is exceptionally difficult and not at all straightforward. Success in either depends critically on access to reliable and well-defined data. But high quality and clear definition, while necessary, are by no means sufficient to render data useful. The data also have to be relevant to the issues policy seeks to address and they have to be accompanied by a credible interpretive framework. These requirements, obvious though they may seem, are very difficult to satisfy. My remarks about these needs and difficulties are based on my own career as a scientist, administrator, and policy advisor, during which I have struggled with policy in nearly every stage of its complex life cycle from conception to death.

In my current role as science advisor to President Bush and Director of the U.S. Office of Science and Technology Policy I am acutely aware that actions of the U.S. government have global impact, and I am deeply motivated to help make those actions as rational as humanly possible. Rationality in action, from my scientist's viewpoint, entails linking actions to empirically validated hypotheses about the behavior of the phenomena whose course over time we wish to influence. I am assuming we have general goals in mind that we want to achieve, and those goals too must be established with some idea of how we can tell if we have met them, or at least are making progress toward them.

Facts do not speak for themselves. They are meaningful only in some explanatory context. *Physicists* are fortunate in having achieved consensus on a nearly comprehensive interpretive framework for the phenomena they observe. *Economists* can mostly understand each other – or at least many of them say they do – and they use a variety of conventional interpretive frameworks, expressed in their most concrete form through mathematical models with parameters that are estimated by matching to data. *Science policy makers* tend to rely on economic models and data when they exist,

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but also employ ad hoc surveys and opinions offered by panels of experts. *Science policy implementers* are usually government employees and elected officials whose information comes from a variety of sources of varying degrees of visibility, with advocacy groups on the high end and science policy technocrats somewhere near the bottom. I would like to change this. I would like to have science policy tools that are so credible that their products are embraced by the advocates as well as the technocrats. I do not expect tools that approach the credibility of Newton's laws or quantum mechanics, but I believe we can move the standards for science policy making and implementing closer to what already exists in the world of economic policy.

Not that all is rosy in that world. *The Economist* magazine published a critique of economic models in its July 15, 2006 issue, recounting infamous wide-of-the-mark model predictions and noting how results, particularly of the "computable general equilibrium" models, tend to mirror the preconceptions of the model-builders. But the report also noted how influential the models are. "Big models, which span all the markets in an economy," said the report, "can make policymakers think twice about the knock-on effects of their decisions." That is a salutary effect, even if the models are not perfect. The report quotes OECD Chief Economist Jean-Philippe Cotis as saying "orders of magnitude are useful tools of persuasion." I agree. Despite their short-comings, economic models have raised awareness of the complexity of economic policy issues, and provided insights into the possible side-effects of policy. "All models," urged the *Economist* report, "should ultimately be seen as pedagogical devices, their calculations a means to the end of helping policymakers think through their decisions."

I am emphasizing models because they are essential for understanding correlations among different measurable quantities, or metrics. The time series of a single metric, of course, says nothing about cause and effect. Its shape – smooth or chaotic, increasing or decreasing – may get us thinking about what is going on, but otherwise it gives little insight. Statistically significant correlations among different metrics do provide clues to an underlying model, but do not necessarily indicate a causal relationship. It is a logical fallacy to regard one metric as "indicating" another just because their time series are correlated. Both metrics could be responding to a third unmeasured or unknown driving force. I am surely not telling this audience anything new, but this fallacy is routinely ignored by advocates, and may lead to bad policies.

For example, several years ago a colleague showed me the results of an unpublished study showing an amazingly strong correlation between U.S. federal spending on non-biomedical research and the number of bachelor's degrees awarded in the physical sciences, mathematics and engineering. No

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similar correlation seems to exist between research funding and degree production in the bio-medical sciences. What does this mean? Can I replace scholarship incentives with R&D spending to adjust the production rate of engineers? The authors speculated about possible extrinsic effects, but did not explore them. This correlation is so strong I would really like to know what is going on. I would like to know what causal factors drive engineering degree production – and indeed production of scientists in all fields – and I need a model relating production to its inputs. Despite the fact that no model exists to explain these data, my colleague, a respected and skeptical scientist (and not an author of the study nor a government employee), was distributing them widely in an advocacy effort to obtain more funding for physical science. For other reasons this is a reasonable policy just now for the U.S., but I was reluctant to use the data without deeper understanding of its significance.

In a more exasperating case of advocacy trumping analysis, advocates have seized upon the downward historical trend of federal support of research per unit of GDP (*i.e.* non-business R&D intensity) in our country as an argument for substantially increasing government research funding. Now OECD analyses have shown that *business* sector investment in research, which is more than twice the government amount, is strongly correlated with productivity. To quote OECD's Chief Economist again: "… growth regressions point to large effects of business R&D spending on productivity." In the U.S., the federal share of *non-business* R&D has steadily increased to all time highs both in absolute terms and as a percentage of the discretionary domestic budget (exceeded only by a spike during the Apollo program in the late 1960's). But the GDP has far outpaced both the discretionary budget and the federal R&D share, which accounts for the declining federal R&D intensity that advocates deplore. (The current ratio of U.S. federal R&D to GDP stands at about 0.7% which is the OECD average. The public-plus-private sum, or total R&D intensity, is fairly stable over time, and the U.S. value of 2.7% is exceeded among large economies only by Japan's 3.1%.) But it is the *business* R&D intensity that really counts here. A declining federal R&D intensity might even be viewed as an indicator of successful policies for encouraging business sector R&D. Perhaps the U.S. is spending as much on federal R&D as it needs to, perhaps more, perhaps less. Undoubtedly it could be spending it more wisely. I can find arguments to support various positions, but the salience of the underlying correlations is low, and very few people who serve on science advisory panels are even aware of them. Advocacy groups tend to ignore detailed statistical analyses, or interpret them to suit their causes.

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Federally funded R&D does play an important role in what some have called the “ecology of innovation,” and we have tried to understand that role so we can work toward an effective distribution of funds among different fields. This is a universal problem for science ministers in every country. We tend to copy from each other and then cite trends in other countries to support our decisions. I am sure many in this audience are aware of the complex and decentralized nature of government-sponsored research in the U.S., which presents huge challenges to rational distribution of resources. Overall science planning and policy-making is accomplished through a bewildering variety of advisory panels, interagency working groups, and Executive Branch policy processes, the most important of which is the annual budget process that synthesizes the proposal presented annually by the President to Congress. In Congress, multiple committees and sub-committees authorize and appropriate funds in an intense advocacy environment from which politics is rarely excluded. Organizing this potential chaos would be easier if we had “big models” of the sort economists use to intimidate their adversaries. More seriously, the entire process would benefit from the level of scholarly activity that exists today in economic policy. Nevertheless, the U.S. does manage to achieve consensus on a number of science policy principles, not the least important of which is the idea that government should fund high risk long lead time basic research and the private sector should fund lower risk short lead time applied research and development. Some of these principles are embedded in the current competitiveness initiative launched earlier this year by President Bush in his State of the Union speech.

The “American Competitiveness Initiative” (ACI)[1] is a multi-component proposal to strengthen long term U.S. economic strength. This proposal is highly visible and is currently receiving favorable attention by Congress. It is notable that the most expensive part of the Initiative is the Research and Experimentation Investment Tax Credit, a tax incentive for business R&D that Congress has tended to pass year by year, but which we would like to see authorized permanently. Given the empirically inferred sensitivity of economic output measures to business R&D intensity, this is a rational policy proposal in the sense I defined earlier in my remarks. The ACI also includes tuning of the federal share of R&D as well as important education, training, and immigration proposals. We believe all these actions will improve the climate for innovation and competitiveness, but they function at a level within the economy that is only very weakly probed by existing empirical studies. We have lots of data, and we have some correlations, but we do not have models that can serve even as “pedagogical devices” for

1. ACI (2006), “American Competitiveness Initiative”, Washington D.C.: Domestic Policy Council, Office of Science and Technology Policy.

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policy formation. Without these the challenge of defending a coherent pattern of actions to improve the framework is daunting.

The ACI seeks to strengthen foundations for future economic performance. Unfortunately, in our era of dynamic change, the empirical correlations that inform the excellent OECD analyses of economic performance are not very useful to science policy makers as guides to the future. They are not models in the sense that they capture the microeconomic behaviors that lead to the trends and correlations we can discover in empirical data. Take, for example, the production of technically trained personnel in China. China is producing scientists, mathematicians, and engineers at a prodigious rate. As a scientist and an educator, I tend to approve of such intellectual proliferation. As a policy advisor, I have many questions about it. How long, for example, can we expect this growth rate to be sustained? Where will this burgeoning technical workforce find jobs? What will its effect be on the global technical workforce market? Is it launching a massive cycle of boom and bust in the global technology workforce? Historical trends and correlations do not help here. Nor, I am afraid, does simply asking the Chinese policy makers what they intend. They also need better tools to manage the extraordinary energy of their society. We need models – economists would call them microeconomic models – that simulate social behaviors and that feed into macroeconomic models that we can exercise to make intelligent guesses at what we might expect the future to bring and how we should prepare for it.

I am under no illusion that either the OECD or any other single organization will be able to produce such models in a single massive effort. But I do believe it is a realistic goal to build a new specialty within the social science community – complete with journals, annual conferences, academic degrees, and chaired professorships – that focus on the quantitative needs of science policy. The U.S. National Science Foundation has launched a program in "the social science of science policy" and important conferences are taking place where such issues are discussed. There are several reasons why this is a good time to encourage such ventures.

First, the dramatic influence of information technology on almost every aspect of daily life, from entertainment to global trade, has made it very clear that technical issues will be an important dimension of nearly all future economies. In this context, science and technology policy acquires an unprecedented significance. Post World War II science policy, at least in the United States, focused on Cold War issues until the late 1980's. The 1990's were a transition decade. Since the turn of the century all science policy eyes have been on technology-based innovation and how to sustain it. Studies of government science investment strategies have a long history, but the

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increased demand for economic effectiveness creates a dynamic in which new approaches to science policy studies will flourish.

Second, in the face of rapid global change, old correlations do not have predictive value. The technical workforce today is highly mobile, and information technology has not only dramatically altered the working conditions for technical labor, but has also transformed and even eradicated the functions of entire categories of technical personnel. Distributed manufacturing, supply chain management, and outsourcing of ancillary functions have undermined the usefulness of old taxonomies classifying work. The conduct of scientific research itself has been transformed, with extensive laboratory automation, internet communication and publication, and massive computational and data processing power. We simply must have better tools that do not rely on historical data series. They do not work anymore. Microeconomic reality has inundated macroeconomic tradition with a flood of new behaviors.

Third, the same rapidly advancing technologies that created these new conditions also bring new tools that are particularly empowering for the social sciences. Large databases and complex models are inherent in social science research. The vast articulation of internet applications makes possible the gathering of socio-economically relevant data with unprecedented speed and affordability, and access to massive inexpensive computing power makes it possible to process and visualize data in ways unimagined twenty years ago. New capabilities for direct visualization of large data sets in multiple dimensions may render traditional statistical methods obsolete. A growing community of scientists from many different fields is inventing data mining and data visualization techniques that I believe will transform traditional approaches to analysis and model-building. These new tools and opportunities can be an invigorating stimulus for all the social sciences, including the social science of science policy.

The themes of this “Blue Sky II” meeting bear directly on the issues that make my job difficult. On behalf of all science policy advisors everywhere, I commend and thank OECD and its committees and the sponsors of this week’s conference for their good work. I look forward to learning more from you about how to improve the empirical basis for science policy.

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Chapter 3

DEVELOPMENTS IN EU STATISTICS ON SCIENCE, TECHNOLOGY AND INNOVATION: TAKING STOCK AND MOVING CLOSER TO EVIDENCE-BASED POLICY ANALYSIS[1]

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3.1. Introduction

In 2000, the Lisbon European Council rightly recognized that Europe's future economic development would depend crucially on its ability to create and develop high-quality, innovative and research-based sectors. European Union (EU) and national action plans were accordingly developed. In view of the scope of the problem, it was clear that tackling the EU's deficient innovative capacity required a longer-term, broad, systemic policy framework. No single action would deliver innovation-based higher growth. Rather, a series of interconnected initiatives and structural changes was needed. In addition to the stimulation of research inputs from the public and private sectors, other structural reforms in product, labour and capital markets became part of the policy agenda. Nevertheless, the EU's research and development (R&D) deficit became a central focus of research policy with the articulation, at the Barcelona European Council in 2002, of a target of 3% of gross domestic product (GDP) for spending on R&D and innovation by 2010, one-third of which was to be publicly financed.[2]

1. The author acknowledges the input from European Commissioner Janez Potočnik's Knowledge for Growth Working Party on S&T Indicators, particularly from V. Duchene (DG Research) and A. Gotzfried (Eurostat).

2. See EUROPA (2002), Presidency Conclusions, Barcelona European Council, March 15 and 16, para. 47, *http://europa.eu/european_council/conclusions/index_en.htm*; accessed March 9, 2007).

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Several years later, Europe's performance in R&D and innovation continues to be disappointing. While there are examples of good performance in particular sectors and member states, overall the EU innovation environment remains weak. If recent trends continue, neither the 2% private nor the 1% public target will be reached by 2010.

With poor results have come fatigue, lack of interest and mounting criticism of policy: insufficient public funding dedicated to innovation; lack of governance; no real commitment beyond rhetoric; incorrect and missing instruments. Evaluations of the EU's innovation policy (such as the Kok Report (EC 2004) and the Aho Report (CEC 2006) have also identified the governance of innovation policy, including the lack of well-informed policy makers, as a major problem.

The way forward for improving innovation policy in Europe lies in better analyses and recommendations to guide evidence-based policy design. Policies need to be supported by analysis, monitoring and evaluation practices, which then feed back into the policy process. This chapter examines the challenges for the statistical system in establishing an evidence-based policy process. The range of current official statistics has improved to some extent, but is still inadequate for measuring the knowledge economy and supporting policy analysis.

The adoption of the EU legal framework for science, technology and innovation (STI) statistics in 2003–2004 constituted a major step forward, because a common methodology for the mandatory provision of statistical data is the basis for EU policy development and understanding. However, the statistics defined in the legislation and the underlying methodology are limited: for R&D statistics, the methodology is based on the Frascati approach to R&D, which is essentially an input approach and therefore lacks the essential features of a systemic framework for policy development and understanding.

Over the past 10 years, some experiments with process indicators (describing knowledge flows or research networks) and micro-level indicators (monitoring the behaviour and performance of key actors, such as firms or universities) have tried to rectify this problem. However, these pilot studies were conducted on an ad hoc basis and have yet to result in internationally comparable data and methodologies.

The aim of this chapter is to indicate the main gaps in the current STI statistics and to propose ways of improving the current situation.

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3.2. What data and indicators are needed?

From a policy perspective on how to improve the EU's economic growth, it is important to broaden the scope of the exercise beyond data and indicators in the area of R&D only. For assessing innovative capacity, defined as the ability of a system not only to produce new ideas but also to commercialize a flow of innovative technologies over the longer term, a range of factors deemed important for effective innovation effort is required. A well-developed supply side of R&D (as reflected in the amount of R&D carried out or the number of skilled researchers involved) is a necessary but insufficient condition for successful innovation. Broader framework conditions are important as well, including sufficient demand for innovation to reward successful innovators. A critical element in the framework is the interconnectedness of the agents in the system, linking the common innovation infrastructure to specific technology clusters. This requires good industry-science linkages and well-functioning capital and labour markets.

From the perspective of innovative capacity, country differences with respect to innovation and growth might reflect not just different assets in terms of labour, capital and stock of knowledge, but also varying degrees of capacity to distribute knowledge (the efficiency of the innovation system). Overall, this discourages an approach that *a)* looks at knowledge creation indicators only; and *b)* looks at statistical indicators individually to assess performance. Rather, it suggests that a systemic approach should be taken towards understanding the relationship between STI and socio-economic development.

The problem with this approach, however, lies in producing empirical approximations of nations' institutional frameworks and capacity to distribute knowledge. The only pieces of statistical evidence available at present are those showing the importance of interactions, such as the availability of venture-backed financing, co-operation on R&D among firms and between industry and science, international co-patenting, and the number of researchers employed by business.

3.3. Taking stock of indicators currently used in the EU policy process

The wide scope of the Lisbon strategy made it necessary to identify and focus on a restricted, well-defined set of targets and policy measures needed to achieve the strategy's objectives, and a corresponding set of indicators to monitor progress on the targets.

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The selection of the indicators is clearly constrained by the availability of data. Time series should be available, timely and comparable across member states, and should include major benchmarks (such as the United States, Japan or China).

3.3.1. Structural indicators

To monitor progress on the principal targets of the Lisbon strategy, the European Commission and Council agreed on a list of main structural indicators. The performance of member states according to these indicators is continually assessed.

For the European Knowledge Area (EKA), R&D and innovation expenditure as a percentage of GDP, with a target of 3% by 2010, is the main indicator. Beyond this, there are other (secondary) structural indicators for the EKA, which are constantly monitored:

- Spending on human resources (public expenditure on education);
- Gross domestic expenditure on R&D (GERD) by source of funds (private/public);
- Level of Internet access: households/enterprises;
- Science and technology (S&T) graduates: total/females/males;
- Patents: European Patent Office (EPO)/United States Patent and Trademark Office (USPTO);
- Venture capital investments: early stage/expansion and replacement; and
- Information and communication technology (ICT) expenditure: information technology (IT)/telecommunications expenditure.

3.3.2. Innovation indicators

For the area of innovation and R&D, the Lisbon European Council requested the development of the European Innovation Scoreboard (EIS) by the Commission's Directorate-General (DG) Enterprise. The EIS contains indicators that have been selected to summarize the main drivers and outputs of innovation. It is a composite indicator application, with a combination of innovation input and output indicators.[3]

3. Composite indicator construction is sensitive to which indicators are included and with what weight. The fact that each of the six publications of the EIS to date (EIS 2006 was released in February 2007) has seen a revision of the composition of the summary indicators suggests that analysts have not fully come to grips with capturing the innovation process into a composite.

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Input indicators include science and engineering (S&E) graduates, the population with tertiary education, broadband penetration rates, public and private R&D, innovation expenditures, ICT expenditures, early-stage venture capital, and small and medium-sized enterprises (SMEs) innovating in-house and co-operating on innovation. Output indicators used are high-technology employment, high-technology exports, sales shares of new-to-market/firm products, and EPO/USPTO/Triadic (US, EU and Japanese) patents, trademarks and designs.

The EIS uses mainly Eurostat data, covering 32 countries. A number of indicators overlap with the EU structural indicators.

3.3.3. Research indicators

In support of the European Research Area (ERA) initiative, DG Research was directed to produce a set of indicators and a methodology for benchmarking research (policies) in the member states. DG Research reports these indicators in the *Key Figures* series. The list includes input and output indicators, very much in line with the EIS. On the input side, they include expenditures on R&D, researchers, new S&E graduates, education expenditures and venture capital investment. On the output side, they include scientific publications, EPO/USPTO/Triadic patents and high-technology trade.

3.4. Evaluating the choice of indicators

3.4.1. Are the right indicators being measured?

Both the structural indicators and those specifically for research and innovation, although restricted by data availability, clearly seem to be motivated by the weaknesses in EU innovative capacity and by the "systems" approach to improving that capacity. Although R&D spending is a central structural indicator, it fits into a set of other indicators, allowing integration with labour, capital and product market reforms.

A key message of a systemic approach is that the effectiveness of innovation systems depends on a balanced combination of creative capacity, diffusion capacity and absorption capacity. These capacities are all somehow reflected in the selected indicators. The targets selected for the EKA, apart from R&D expenditure, show the central importance of a highly educated labour force in the EU's creative and distributive capacities. They also reflect the specific significance of ICT expenditure in the EU's growth agenda as an investment in a general-purpose technology and acknowledge the importance of financing for innovation.

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Nevertheless, some important areas are not covered.

3.4.1.1. Linkage indicators

The area of indicators that is least represented is industry-science links. The lack of industry-science linkage indicators is especially disturbing since this is one of the particular deficiencies of EU innovative capacity (*cf.* the European "research paradox"[4]). What is missing in the set of main indicators are those on, for instance, co-operation, co-patenting and co-publishing between firms and research institutes, researcher mobility between industry and science, private funding of basic research, patenting by universities and public research institutes, and university spinoffs. This is due partly to a lack of data, but clearly more could be done (see below).

3.4.1.2. Economic incentives and institutional regimes

The business environment in which potential innovators operate is important for their chances of commercializing their innovations successfully. It includes regulatory barriers, openness to national and international competition, ease of entry, and effective protection of intellectual property. This area is seriously underdeveloped in the current work on innovation indicators. Again, this is due partly to a lack of data, but more could be done here too.

3.4.1.3. Connecting national/EU innovative capacity to the global system

The collection and monitoring of innovative capacity indicators are carried out predominantly at the national level. But clearly, economic agents, and particularly large firms, which drive nations' innovation potential, are increasingly operating transnationally. This has important implications for the performance of national innovation systems: *a)* relevant actors include foreign actors operating in or linked to national innovation systems; and *b)* national actors are operating in or linked to other innovation systems. Both of these factors are likely to have an impact on the performance of a national system. Currently, there is a lack of indicators tracing the international activities of actors and their links to national innovation systems.

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4. Soete (2006) defines the European "research paradox" as "the fact that contrary to economic theory and intuition, a strong scientific research base does not appear to go hand in hand with strong technological and economic performance, rather the contrary" (214).

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3.4.2. Are the indicators being measured at the right level of aggregation?

3.4.2.1. Sectoral/technological level

Underlying any aggregate innovation indicator is the structural makeup of the economy, which differs greatly among EU countries. Such structural differences can play an important role in explaining some of the differences in innovation performance. The main reason for this is that there is a great deal of diversity among industrial sectors and technologies in terms of innovation process, and innovation inputs and outputs. Technological opportunities differ across sectors, with ICT as a prime example of a high-growth sector with huge potential for technological advance. Other major sectoral differences are the size of the innovating unit, the ease and methods of appropriation, and the motives for innovation (product versus process innovations). There is also a great deal of diversity among the sources of innovation, ranging from in-house R&D laboratories, through suppliers and users, to public research institutes for the industries using science-based technologies. This implies that there will be major sectoral differences in many of the indicators used. Unfortunately, high-quality data at the sectoral/technological level for some key variables are lacking.

3.4.2.2. Regional level

Innovation policies are often developed and implemented at the regional level, in addition to the national and EU levels. Regional indicators can help to inform these policies. The Commission is planning a biannual Regional Innovation Scoreboard (RIS), starting in 2007, but again data constraints are seriously limiting the scope of this exercise.

3.4.2.3. Micro-level

S&T indicators need to measure a wider range of actors, such as universities, research institutes, transfer platforms, start-ups, small innovative firms, multinationals and venture capital firms. Understanding what drives their behaviour is an important component in understanding the performance of the aggregate system. Hence, more information is needed at the level of individual actors on relevant parameters (for instance, competencies, motives, performance) and relationships (financial, flow of personnel, strategic coordination and so on).

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With respect to firms, several surveys and questionnaires (the Organisation for Economic Co-operation and Development (OECD) R&D survey, the Community Innovation Survey (CIS) and the R&D Scoreboard, which is based on company account information) can use the individual firm as the unit of analysis.

3.5. The way forward

A smooth process of evidence-based policy analysis is still a distant prospect. Work to be done includes: *a)* improving the basic indicators for innovation input and output; *b)* developing new indicators; and *c)* disaggregating the data reporting at the sectoral/technological, regional and institutional levels.

The following sections describe the current work in these areas.

3.5.1. Improving basic indicators

3.5.1.1. Monitoring the business enterprise sector's contribution to R&D financing

The "Barcelona 3% Objective" (3% of GDP to be devoted to R&D) refers to the execution of R&D, while the "Barcelona 2/3 Objective" (two-thirds of total expenditure on R&D to be funded by the business enterprise sector) refers to the source of funding. According to the *Frascati Manual* (OECD 2002) and the Commission Regulation (EC) 753/2004, expenditure on R&D can be broken down and analyzed by sector of performance (the sector in which R&D activities are executed) and, for each sector of performance, by source of funding (the sector financing the execution of R&D).

The monitoring of the "Barcelona 2/3 Objective" has been incomplete, since "R&D funded from abroad" is not split into private and public spending. There is a need to urge national statistical offices to obtain a more complete matrix, and to try to make these data mandatory under the next revision of the regulation (from 2007 onwards).

3.5.1.2. Public expenditure on R&D

When policy analysts monitor the public funding of R&D (the so-called "Barcelona 1/3 Objective"), the indicator that is characteristically used is "GERD, financed by government." This information typically becomes available for analysis only after considerable delay. Government budget appropriations or outlays for R&D (GBOARD) data provide information on public budgets for R&D that is available more expeditiously. These data are

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therefore an interesting source for monitoring public efforts on R&D. GBOARD and GERD statistics are commonly used in a complementary manner, although they differ in two fundamental ways: *a)* unlike GERD, GBOARD provides public budget figures, and no expenditure data; and *b)* GERD is solely domestic, whereas GBOARD may include international co-operative initiatives, such as the European Space Agency (ESA) or the Airbus program.

The correlation between the two series (by country and across time) is very weak. To improve their correspondence, better and internationally harmonized procedures for labeling R&D expenditures need to be agreed. More work can be done to harmonize the extensive policy information contained in distributions of R&D budgets according to institutional or thematic categories, starting with a revision and better use of the NABS (Nomenclature for the Analysis and Comparison of Science Budgets and Programs) system to classify GBOARD by socio-economic objective. This would, *inter alia*, allow an analysis of how much public funding is allocated to more basic research versus applied research.

3.5.1.3. Scientific output

Bibliometric statistics on publications and citations are analyzed as a proxy for scientific productivity. At the moment, the most highly recognized databases relating to scientific publication and citation data are owned by Thomson ISI. There are some drawbacks and limitations with regard to the sampling frames of the journals and papers, but there are, as yet, no better sources of information at the global level, particularly with regard to citations. The diffusion of these privately held data for use in (policy) analysis has so far been very limited.

3.5.1.4. Technological output: patents

In 2004-2005, the international Patent Statistics Task Force (on which various international organizations, as well as DG Research and Eurostat, are represented) was entrusted with the establishment of an internationally harmonized raw data source on patents: PATSTAT. The EPO committed itself to biannual delivery of a harmonized raw dataset, which would then be used for data production by the OECD, Eurostat and others. This effort has already led to increased data cleaning and production at Eurostat. The PATSTAT raw data file can be further exploited by improving the break-down of data according to type of institution and by building in linkages to other datasets.

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3.5.1.5. Researchers

Information on researchers broadly covers three areas: the number of researchers and their variations (stocks); their mobility patterns (flows); and the reasons why they are moving (motivational aspects and career paths). At the European level, the information on researcher stocks is acquired through various channels: *a)* the R&D statistics collected by Eurostat/OECD; *b)* the Community Labour Force survey; and *c)* surveys on doctorate holders, widely spread among European countries. The areas where data are unfortunately very poor, but where they are nevertheless relevant for policy making are mobility of researchers (internationally and intersectorally) and researchers' career paths. Statistics on the careers of doctorate holders (CDH) are coordinated internationally (involving Eurostat, the OECD and the United Nations Educational, Scientific and Cultural Organization (UNESCO)). Surveys on doctorate holders currently exist in several countries, but with various objectives, populations (doctorate holders, graduates, etc.) and frequencies. As a consequence, information is currently unusable for international comparisons. In response to the needs expressed by users, a process was set in motion to develop an internationally standardized CDH survey. Eurostat will propose a legal basis for this survey (as for the R&D survey). This would mean that it would be mandatory for all European countries to provide the data.

3.5.2. Developing new indicators

3.5.2.1. The process of knowledge creation and diffusion

A new category of indicators has been emerging since the late 1990s that attempts to describe the process of knowledge creation and diffusion within the systems of innovation. Such indicators permit the analysis of the existence of networks of researchers/inventors, and the extent to which the industrial base makes use of the results of scientific work for its innovation activities.

A great deal of work is being done in this field, particularly on:

- Co-publishing activities;
- Co-patenting activities;
- Patent-to-patent citations/references; and
- Patent-to-non-patent citations/references (*e.g.* scientific publications).

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In addition, concordance tables linking NACE (Classification of Economic Activities in the European Community) sectors and International Patent Classification (IPC) codes, and concordance tables linking NACE sectors, OECD field of science and technology (FOS) and UNESCO fields of education have been developed with the aim of providing greater insight into the S&T links of industrial sectors.

Although most of these studies provide new and extremely valuable insights, there is still a lack of coordination of and harmonization among the methods and approaches taken, resulting in a lack of comparability across time and space. More work is needed on better integration of the ad hoc studies' results into official statistical systems.

3.5.2.2. The international flow of R&D investment

With regard to the international flow of R&D spending, the major gap in current information concerns R&D expenditure by EU companies outside their territory, and particularly outside the Triad. The Draft Regulation of the European Parliament (EP)/Council on Community Statistics on the Structure and Activity of Foreign Affiliates (the FATS Regulation), which was close to final adoption in February 2007, includes the collection of R&D expenditure data for "inward R&D" (R&D spending in the EU by affiliates of foreign companies), but does not anticipate any data collection on "outward R&D" (R&D expenditure by EU member states abroad). A major barrier to the dissemination of these data seems to be poor coverage and quality.

3.5.3. Disaggregating the data

3.5.3.1. Sectoral/technological data

The interest in, and use of, sector-specific R&D policies and specialization are hampered by the fact that the current NACE classification is inappropriate for measuring the knowledge economy and society. In particular, *a)* there is a lack of national and international consistency in the application of NACE and North American industrial classifications, especially with respect to the service sector; *b)* the current levels of aggregation in the NACE codes do not serve the purpose of R&D specializations (*e.g.* pharmaceutical preparations and basic products should be listed along with the aggregate "manufacture of chemicals and chemical products"); and *c)* there are not yet internationally standardized and commonly used classification and reporting by technology area with respect to technology-specific information, of relevance for analysis in the fields of, for instance, biotechnology, nanotechnology, new materials and ICT.

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The sectoral activity classification NACE/ISIC (International Standard Industrial Classification of All Economic Activities) is currently being revised to create the second version of NACE (NACE Rev2). This improved activity classification will respond more effectively to the requirements of measuring the knowledge economy and society by rebalancing the classification towards services. Eurostat and the OECD plan to implement the new NACE classification for R&D statistics from the reference year 2008 onwards. This should considerably improve the usefulness of sectoral R&D data.

3.5.3.2. Micro-data

In recent years, several new indicators and statistical bases have been developed that describe or measure firms' behaviour in S&T systems. Nevertheless, the collection of more micro-data and the linkage of several micro-data sources would open up more opportunities in this area. If firm identification were more standardized, information (for example, on patents, R&D budgets, innovation, value added, trade, employment) could be pooled across surveys and other databases.

For non-profit agencies such as universities and research centres, the OECD collects and reports aggregate information on R&D budgets and personnel. Disaggregating this information to the level of individual organizations is hampered by too many differences in data collection across countries. The survey on R&D expenditures in the non-profit sector is less internationally standardized than surveys for the profit sector.

In addition to the official surveys, there are a number of ad hoc surveys on individual units (*e.g.* surveys of Technology Transfer Offices (TTOs)). Most of these initiatives, however, have been developed without co-ordination at the international level. As a consequence, most of them cannot yet provide sufficient comparability across countries and periods. There is a need for the European Statistical System (ESS)/Eurostat and the OECD to get more involved in this area.

3.6. Conclusion

There is clearly much work to be done in the area of S&T-relevant statistics: *a)* improving the quality of existing data and indicators; *b)* developing new series of indicators for new areas; *c)* developing more disaggregated sets of indicators; and *d)* improving the linkage of data and indicators.

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But in addition to producing better S&T statistics, it is important to improve the diffusion of those statistics. Data should be more easily accessible to the relevant users – not only policy makers, but also researchers, who serve as important intermediaries in processing the information for policy analysis. Allowing researchers easier access to data is therefore an important factor in achieving more evidence-based policies.

In general, the process of creating and diffusing S&T statistics should be less linear and more interactive. Users/researchers should be more actively involved in the design of S&T statistics, so that they can not only inform the statistical system of user needs, but also better understand the system's technical constraints.

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Part Three

INNOVATION: CAN SOMETHING NEW BE MEASURED?

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Chapter 4

INNOVATION SURVEY INDICATORS: WHAT IMPACT ON INNOVATION POLICY?

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4.1. Introduction

The first Blue Sky conference in Paris in 1996 introduced a wide audience to some of the results of the first Community Innovation Survey (CIS) from 1993, which was arguably one of the most comprehensive major sources of new innovation data at the time. The purpose of the CIS and other innovation surveys based on the first edition of the *Oslo Manual* was to overcome some of the limitations of the research and development (R&D) surveys. Two main goals were to provide data on innovative activities that were not based on R&D and to provide output measures of innovation.

The CIS is now implemented every two years in all member states of the European Union (EU). The results of the fourth CIS, covering innovation activities between 2002 and 2004, became available in 2006 and 2007. The fifth CIS was in the field in early 2007 and planning for the sixth CIS, which will implement the recommendations of the third edition of the *Oslo Manual* (OECD/Eurostat 2005), is underway.

With results from up to four consecutive surveys, one would think that the CIS would play an essential role in assessing and developing innovation policy. Unfortunately, this has not happened to the extent anticipated in 1996. European policy largely relies on long-established indicators for R&D. These indicators are excellent measures of formal, creative activities to develop innovations in-house, particularly in manufacturing. However, the CIS collects data on four characteristics of innovation in modern knowledge economies that are not adequately covered by R&D indicators: the diffusion of technology, the role of 'distributed knowledge bases' in sharing information of value to innovation (Smith 2002, 2004), the continual increase in the economic importance of the service sector, and the importance to many

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firms, in both the manufacturing and service sectors, of informal innovative activities that are not based on R&D.[1]

This chapter examines why R&D indicators still dominate innovation policy making in Europe and makes several suggestions for improving the usefulness of the CIS. This requires returning to some of the original goals of the CIS and using the CIS to construct new indicators that better meet the needs of the policy community.[2] Several examples of new indicators are provided, including an output measure with better international comparability, an indicator for knowledge diffusion, and a set of indicators for firms' innovative capabilities.

4.2. The policy context for innovation indicators

Between 2004 and 2006, the author and colleagues at UNU-MERIT[3] interviewed 67 members of the policy community – 55 from 15 European countries and 12 from Canada, Japan, Australia and New Zealand – on their use of and need for innovation indicators. R&D indicators were the most widely used and were considered to be the most valuable. In contrast, only a minority of respondents referred to the use of indicators drawn from the CIS or similar innovation surveys in policy making or evaluation.

Within the EU, there are two main reasons why the policy community strongly emphasizes R&D indicators over innovation survey indicators. The first is due to the continuing power of the linear model of innovation, while the second is due to the structure of innovation support programmes.

4.2.1. The case for R&D indicators

A major factor in the continuing popularity of R&D indicators is the key role that R&D plays as the source of inventions in the science-push or linear model of innovation. The countless announcements of the death of this model and its presumed replacement with "systemic" models using Schumpeterian definitions of innovation are decidedly premature. The continuing influence

1. Bell (2006), using data from the SESTAT survey for the United States, estimates that two-thirds of scientists and engineers in the private sector are not employed as researchers. Many of them could be involved in informal activities to develop or implement innovations.

2. Godin (2002) comments that the innovation surveys "ended up measuring innovation the way they measured R&D, *i.e.* in terms of inputs and activities," rather than fulfilling their original goal of measuring outputs. The view of this author is that the design of the CIS questionnaire is compatible with the original goal. The problem is in how the data are used.

3. United Nations University – Maastricht Economic and social Research and training centre on Innovation and Technology.

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of the science-push model has arguably hindered policy interest in a wider range of CIS indicators.

Academic research using CIS data has not managed to overcome the policy focus on the science-push model of innovation because most academic research has also focused on R&D. A UNU-MERIT analysis of 176 academic papers in English using CIS data found that only 5% explored innovation strategies, performance, or other characteristics of innovative firms that did not perform R&D, although many of them look at knowledge sharing from a systemic perspective.[4] In addition, academic research based on the CIS has not been widely used by the European policy community. The UNU-MERIT interviews found that policy analysts rarely use this body of research because academic papers are not focused on their needs. Out of the 176 academic papers using CIS data, only 21 (12%) were found to make any policy recommendations. Most of these 21 papers included only a few sentences or a single paragraph that discussed the policy relevance of the results. One of the problems, as pointed out by Veugelers and Cassiman (2005), is that CIS results for one country do not provide a strong basis for policy development. Policy-relevant results need to be replicated across several countries, but this is difficult due to data access restrictions that usually limit access to CIS data to one country.

The second reason for the policy focus on R&D indicators is due to the dominance of supply-side R&D support programmes in innovation policy. An example is the Lisbon Agenda, and specifically the Barcelona European Council's initiative to solve the EU's decline in competitiveness with a proposal to increase European R&D intensity to 3% of gross domestic product (GDP) by 2010. This fixation on R&D has probably delayed the slow progress made over the 1990s towards an expanded view of innovation that includes informal activities[5].

The dominance of R&D support programmes in documents and political discussion also reflects the distribution of public funds for different types of innovation policies. Although there are no official statistics on the amount of funding for R&D versus other types of innovative activities, some relevant data are available on the Trend Chart website, which maintains an extensive database of innovation programs in each of the EU member states. A thorough search of the database in September 2006 identified 54 programs that did not necessarily involve R&D. These largely consisted of programs to fund the

4. The UNU-MERIT database is maintained by Dr. Cati Bordoy and includes all papers, in English, presenting microeconomic analyses of data from CIS1 through CIS4. The database was last updated in January 2007.

5. An example is the influential 2005 *Green Paper on Innovation*, which noted the importance of including innovation activities other than R&D (CEC 2005).

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diffusion of technology and skills, particularly to small and medium-sized enterprises (SMEs).[6] It is unlikely that this covered all non-R&D innovation programs, but it should have captured the range of programs on offer. Annual expenditure in euros was available for 85% of the 54 programs, which covered the following areas:

- Training staff from SMEs, particularly in technology requirements and innovation management;
- Technology adoption subsidies, particularly for modernization;
- Subsidies to acquire licences to new technology;
- Subsidies to hire skilled science and engineering (S&E) staff; and
- Manufacturing extension services to help identify firms' needs for new technology.[7]

These five policies are likely to be most relevant for SMEs that do not perform R&D or which have low innovative capabilities. On average, the 10 states that joined the EU in 2004, plus Greece and Portugal, spend eight times more on a per capita basis on these types of programs than the more developed EU member states, but overall these programs account for less than 2% of EU public expenditures on R&D. Even allowing for substantial under-reporting in the Trend Chart database, programs to support innovative activities that do not involve R&D probably account for less than 5% of all government support for innovation.

The low public investment in these types of programs suggests that indicators for innovation activities that are not based on R&D, such as the diffusion of technology and skills, will never be as important to the policy community as R&D indicators, with the possible exception of the 10 member states mentioned above. However, such policies could be relatively more important to SMEs (a target of many policy actions) than the low investment would suggest. An Innobarometer survey in 2004 asked a sample of 4 534 innovative SMEs, covering all 25 EU member states at the time, if any of eight types of innovation support programs were "crucial to any of your innovation projects, such that the innovation would not have been developed without the support." Almost a third (31.5%) of respondent SMEs that used two or more innovation support programs cited support for collaboration as

6. See *http://trendchart.cordis.lu/*

7. Most EU countries support a system of regionally based technology transfer or innovation offices to provide support and technical advice, such as the Manufacturing Advisory Service (MAS) in the United Kingdom or OSEO-ANVAR in France. They provide general education programs, including demonstration projects, visits to successful innovative firms, help with identifying relevant new technology and courses on innovation management.

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crucial, followed by programs to support research (cited by 25%) and the adoption of process technology (cited by 14%) (Arundel 2004). The latter is supported by several of the five types of programs listed above, while the first and fourth programs can be relevant to collaboration by improving a firm's innovative capabilities.

Increased interest in the role of demand in innovation could also lead to greater interest in diffusion indicators. Both the influential Aho Report (CEC 2006) and the Competitiveness and Innovation Framework Program (CIP) (CEC 2005) stress markets and demand, including the role of lead users, and discuss the need to increase the rate of adoption within Europe of information technology in the service sector. The CIP proposal observes that "making innovation work means innovation capacity building, the uptake of new technologies and of existing technologies in a new context and carrying them through to the business level." To achieve these goals, the CIP proposes an entrepreneurship and innovation program to support the transfer of technology, the uptake of technologies and applications, and co-operation between universities and firms. Two other sections of the CIP proposal support the adoption of information and communication technology (ICT) and the creation of markets for sustainable production methods and energy-efficient technology.

The Aho Report and the CIP proposal are hopefully part of a gradual shift in Europe from supply-side support for the creation of new ideas through R&D to a concerted effort to ensure that these ideas also find their way to firms that can apply them to their new products, processes and services. This shift was also reflected in the UNU-MERIT interviews. The interviewees were asked an open-ended question about the types of new indicators that they would like to have. The most frequent request was for indicators for the process of commercialization and collaborative activities involving innovation. The latter was of the greatest policy interest, cited by interviewees from all but two of the 19 countries.

4.3. Improving the relevance of the CIS

An analysis of the interviews, program funding, and several major innovation policy documents indicates that R&D activities will remain the core focus of innovation support programs in Europe. Nevertheless, the policy community is interested in better indicators for activities such as commercialization and collaboration, which will involve both R&D performing firms and firms that use other methods to innovate. As recognized by the Aho Report and the CIP proposal, European competitiveness will depend on both R&D *and* on the diffusion and application of new technology (which may or may not involve R&D).

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The CIS and similar innovation surveys can provide useful indicators for both sets of policy needs, but this will require the development of new indicators, in addition to the indicators that are currently publicly available, for instance on Eurostat's New Cronos Web site or in the Eurostat publication *Innovation in Europe* (EC 2005). The existing set of indicators is not adequate because the indicators either lack sufficient detail to meet policy requirements or they do not provide the type of information required by policy. For instance, very few indicators are provided separately for both R&D performing and non-R&D performing firms. This reduces the value of many indicators for developing innovation policy for both groups.

One solution is to develop complex indicators based on the responses to more than one survey question. Complex indicators can reveal much more about firms' innovation activities and strategies than simple indicators based on the frequency of responses to a single question.

This section gives examples of new complex indicators for new-to-market innovations, knowledge diffusion and innovative capabilities. All three examples were inspired by the interviews with the policy community and are based on an analysis of the micro-aggregated CIS3 data that were released by Eurostat in July 2006.[8] A major drawback is that the dataset contains results for only two highly developed countries, Belgium and Iceland, and for 10 less innovative EU member states – another illustration of the problem with access to CIS data. Nevertheless, the results demonstrate the possibilities of using the CIS to construct new indicators.

The new indicators described below use only non-interval-level data with high response rates to a specific question and are weighted to reflect the population of firms in each country. The three examples concern how firms innovate, but only the third example is directly linked to R&D. The relevance of the other two proposed indicators could be improved by providing separate results for both R&D and non-R&D performing firms.

4.3.1. New-to-market innovations

The published CIS indicators include an output indicator for the innovation sales share[9], defined as the percentage of total product sales, aggregated across all firms, from products that were "new to the firm's market." Using CIS3 data, the best-performing European countries for the innovation sales share were Spain with an innovation sales share of 16.3%, followed by Finland (14.5%) and Portugal (10.8%). In comparison, percentages

8. All results are weighted to reflect the population of firms in each country.

9. This indicator is included in DG Enterprise's European Innovation Scoreboard (see *www.proinno-europe.eu/doc/EIS2006_final.pdf*, last accessed April 22, 2007).

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were much lower for Germany (6.2%), France (5.8%), Belgium (5.1%), the Netherlands (3.1%) and the United Kingdom (1.7%).

These results are puzzling and tend to reduce confidence in the CIS. No one expects Portugal's performance on this indicator to be more than three times better than the Netherlands and more than five times better than the United Kingdom. The explanation is that the question asks about sales from products that were new to a *firm's* market. Portuguese and Spanish firms could have outperformed the Netherlands and the United Kingdom because they were introducing innovations, already available on other markets, to a less developed domestic market. Furthermore, a firm need not have developed the innovation in-house through R&D, but could simply have been passing on an innovation that had been developed by another firm based in a different market. Consequently the combination of results for R&D and non-R&D performing firms is misleading.

The problems with this indicator can be partially rectified by building a complex indicator that includes data from a CIS question on the firm's market: local, national or international.[10] A reasonable assumption is that firms that have introduced a new-to-market innovation *and* are active on international markets are subject to greater competition, and therefore new-to-market innovations will be more comparable among firms based in different countries. A second step, not explored here, is to provide separate indicators depending on how firms innovate (see section 4.3.2 below).

Table 4.1 presents results for three new-to-market innovation indicators. Column A, the publicly available indicator for the innovation sales share, shows that firms based in Spain, Portugal, Romania, the Czech Republic and Slovakia performed better than firms based in Belgium. Belgium's relative performance improves for the percentage of firms that introduced at least one new-to-market innovation (column B). Column C gives the results for a complex indicator: the percentage of firms that introduced any new-to-market innovations *and* were active on an international market.[11] In Belgium, 8.2% of firms meet these requirements, compared to only 1.2% of firms in Spain. Belgium is the leading country for this indicator, whereas Spain is the second worst performer after Bulgaria. These results suggest that Spain's high performance for the innovation sales share was from product sales on the domestic market that may already have been available

10. The question asks for the firm's main market. An international market can include a neighbouring country. Responses to the CIS4 questionnaire will provide more accurate results because it asked about local, national, other EU, and non-EU international markets.

11. Given full interval-level data, the indicator can be calculated as the share of total product sales from new-to-market innovations by firms active in international markets.

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on other markets. In general, the complex indicator in column C provides results that should be considerably more comparable across countries.

Table 4.1. New-to-market innovation indicators

		A Innovation sales share	B Any new-to-market innovation	C Any new-to-market innovation *and* active on an international market	Ratio C/B
Belgium	BE	5.1	18.0	8.2	0.45
Bulgaria	BG	2.1	6.3	1.0	0.17
Czech Republic	CZ	7.2	12.3	7.4	0.61
Estonia	EE	4.5	13.9	4.7	0.34
Greece	GR	2.9	11.3	2.2	0.19
Iceland	IS	2.0	11.1	2.9	0.26
Latvia	LV	2.3	17.8	6.4	0.36
Lithuania	LT	4.3	13.1	2.7	0.21
Portugal	PT	10.8	19.8	4.4	0.22
Romania	RO	7.8	13.8	3.5	0.25
Slovakia	SK	6.2	8.0	3.4	0.43
Spain	ES	16.3	11.3	1.2	0.11

Source: CIS3 micro-aggregated data referring to innovation activities in 1998–2000.

4.3.2. Knowledge diffusion

Knowledge diffusion is an essential aspect of innovation by both R&D performing and non-R&D performing firms. It includes: the acquisition of knowledge that does not require interaction with the source,[12] such as the purchase of capital goods or services, including the licensing of intellectual property; the acquisition of knowledge that is freely available from sources such as scientific publications or through attendance at trade fairs; and the acquisition of tacit knowledge obtained directly from other people through collaboration. The third edition of the *Oslo Manual* (OECD/Eurostat 2005, 82) stresses the importance of collecting information on each of these three methods of knowledge diffusion.

12. A good indicator for the first kind of diffusion could be produced using expenditure data on the acquisition of machinery, equipment and software. The equivalent CIS3 data have not been used because of a high non-response rate to this question, but the response rate in CIS4 appears to have improved substantially.

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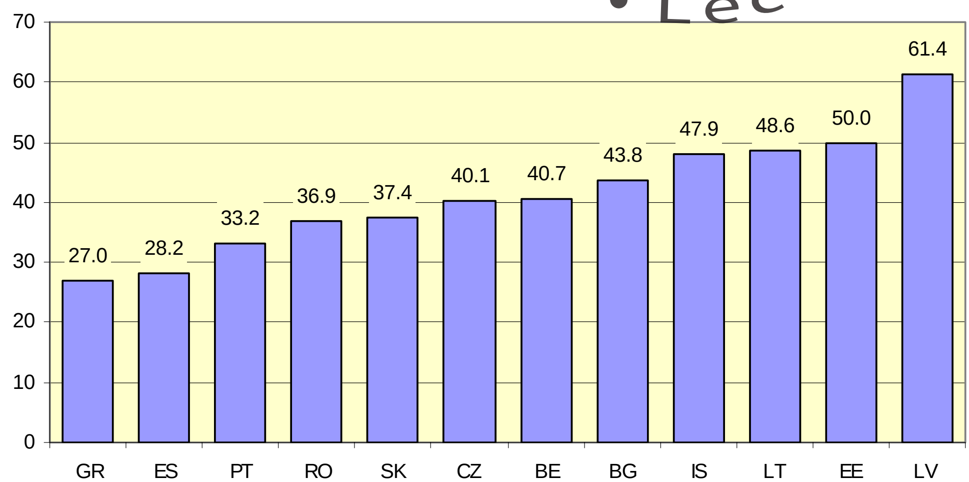
These three types of diffusion can be subdivided into two groups: active knowledge diffusion, in which firms develop innovations through interaction and collaboration with other firms or institutions; and non-interactive knowledge diffusion, in which firms obtain external knowledge only through open sources or through the purchase of technology.

The CIS3 can be used to identify active knowledge diffusion, defined here as a positive response to one or more of three questions: *a)* Were the firm's *product* innovations developed mainly in co-operation with other enterprises or institutions? *b)* Were the firm's *process* innovations developed mainly in co-operation with other enterprises or institutions? *c)* Did the firm have one or more co-operative arrangements on innovation with other enterprises or institutions? The results of the analysis are given in Figure 4.1.

Figure 4.1. Percentage of innovative firms developing innovations through collaboration (active knowledge diffusion)



Source: CIS3 micro-aggregated data referring to innovation activities in 1998–2000.

Other types of indicators for knowledge diffusion can also be constructed. For example, it is possible to combine knowledge diffusion through both technology adoption and active collaboration by including firms that gave a positive response to the question about the acquisition of advanced machinery and equipment, or that reported that their product and process innovations were developed mainly by other firms. Such an indicator can identify the importance to firms of all types of knowledge diffusion. For the 12 countries in the dataset, 78.7% of firms reported innovating through one or more

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diffusion-based methods, highlighting the crucial importance of knowledge diffusion to innovation.

4.3.3. Innovation modes

The *Oslo Manual* defines a firm as innovative if it has introduced at least one product or process that was new to the firm itself. This means that no distinction is made between firms that purchase new technology off the shelf with minimal effort and those that have extensive in-house R&D projects to develop innovations. Although this indicator is widely available, it is of limited value to policy because it combines firms with very different methods or modes of innovating. An increase or decrease in this indicator does not necessarily mean that innovation support policies have succeeded or failed: for example, a decrease in the share of firms with highly developed innovative capabilities combined with an increase in minimally innovative firms could produce a net increase.

The solution to this problem is to develop a set of indicators that describe *how* firms innovate, using a methodology that assigns all CIS respondents to one, and only one, category. Previous research has taken this approach (Tether 2001; Arundel and Hollanders 2005), but the relevance of the results was hampered by using categories that did not closely reflect policy needs or by using questions with high non-response rates, requiring complex and non-transparent statistical routines to assign all firms to the most appropriate innovation category.

The method proposed here and summarized in Figure 4.2 avoids the non-response problem by using only nominal-level questions and improves policy relevance by focusing on two innovation characteristics that, according to the UNU-MERIT interviews, are important to European policy: collaboration, and formal in-house innovation based on R&D (or proxied through patenting). The first axis for this indicator refers to whether or not a firm was involved in active knowledge diffusion through collaboration (defined in section 4.3.2). The second axis refers to whether or not the firm had formal in-house creative activities, measured by its response to one of two questions: *a)* Did the firm perform R&D? or *b)* Had the firm applied for at least one patent? Those that responded positively are defined as "inventive" firms that were most likely to produce innovations containing a major technical advance. Those that did not answer either question positively were informal innovators with the ability to develop innovations on an ad hoc basis, such as through production engineering. It should be noted that Figure 4.2, and the results given in Table 4.2 and Figure 4.3, exclude non-

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innovative firms, which account for a large share of all firms in several of the less innovative countries.[13]

Figure 4.2. Innovative firms' methods of innovation

	Non-collaborators	Collaborators
Informal innovation activities	**A.** Informal non-collaborators **41.4%** *(8.9% were technology adopters)*	**B.** Informal collaborators **15.8%**
Formal innovation activities	**C.** Formal non-collaborators **24.7%**	**D.** Formal collaborators **18.1%**

Source: CIS3 micro-aggregated data referring to innovation activities in 1998–2000.

Note: Percentages in bold sum to 100% of all innovative firms.

Cell A: Firms that only reported informal innovation activities in-house and had no innovation activities based on collaboration or co-operation with other firms or institutions.

Cell B: Firms that only reported informal innovation activities in-house, but collaborated or co-operated with other firms or institutions to develop innovations.

Cell C: Firms that reported formal innovation activities (performing R&D or applying for a patent), but had no innovation activities based on collaboration or co-operation with other firms or institutions.

Cell D: Firms that reported formal innovation activities (performing R&D or applying for a patent) and collaborated or co-operated with other firms or institutions to develop innovations.

The goal for policy is to increase innovative capabilities by shifting the national distribution of innovative firms towards quadrant D in Figure 2, and to encourage non-innovative firms, particularly in less innovative countries, to enter one of the four innovative categories. Of note, the group represented in quadrant A, which has the largest share of innovative firms, includes firms that only innovate through adopting technology developed by other firms or institutions (technology adopters).

Table 4.2 gives some characteristics of the four groups of innovative firms, with separate results for the technology adopters in quadrant A of Figure 2. Compared with the average, a significantly lower proportion of firms in quadrant A was active on international markets, had sourced external knowledge (although almost all innovative firms derived some knowledge for their innovation activities from external sources) and had introduced both a product and a process innovation. These results suggest that the informal non-collaborators had fewer intensive innovation activities than the

13. The share of non-innovators was 50% in Belgium, 88.4% in Bulgaria, 68.1% in the Czech Republic, 63.4% in Estonia, 71.9% in Greece, 46.7% in Iceland, 60.8% in Latvia, 71.8% in Lithuania, 54% in Portugal, 82.8% in Romania, 80.4% in Slovakia and 66.9% in Spain.

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other groups, but some of them could have had reasonably advanced innovative capabilities.

Table 4.2. Characteristics of innovative firms

	A-1 Informal non-collaborators	A-2 Technology adopters	B Informal collaborators	C Formal non-collaborators	D Formal collaborators
International market[1]	17.4%	9.5%	22.7%	25.5%	36.9%
Source external knowledge[2]	82.8%	82.5%	88.6%	89.2%	95.8%
Product innovator	66.0%	52.8%	64.1%	85.1%	85.9%
Product & process innovator	31.2%	10.9%	42.1%	43.3%	64.4%

Source: CIS3 micro-aggregated data referring to innovation activities in 1998–2000.

1. Firm's main market.

2. Gave a rating of "high" or "medium" importance to at least one of seven external knowledge sources for their innovation activities: suppliers, customers, competitors, universities, government research institutes, conferences/ meetings/journals and fairs/exhibitions.

Figure 4.3 shows that there are large differences by country in how firms innovate. For example, compared with Belgium, Spain and Greece had low percentages of innovative firms that collaborated on innovation, particularly firms that engaged in formal innovation activities. Almost all innovative firms in Bulgaria innovated through informal non-R&D-based activities, whereas this proportion was much lower in Belgium and Greece.

The information in this indicator on the distribution of firms' innovative capabilities should help policy analysts to acquire a better understanding of national innovative capabilities and to develop policies that can shift firms' capabilities towards greater collaboration and formal innovation activity. The indicator should also be directly relevant to the policy community because it identifies R&D and non-R&D performing firms and the incidence of collaboration in both groups. As shown in Table 4.2, both R&D performance and collaboration are associated with a higher incidence of activity on international markets, product innovation, and combined product and process innovation.

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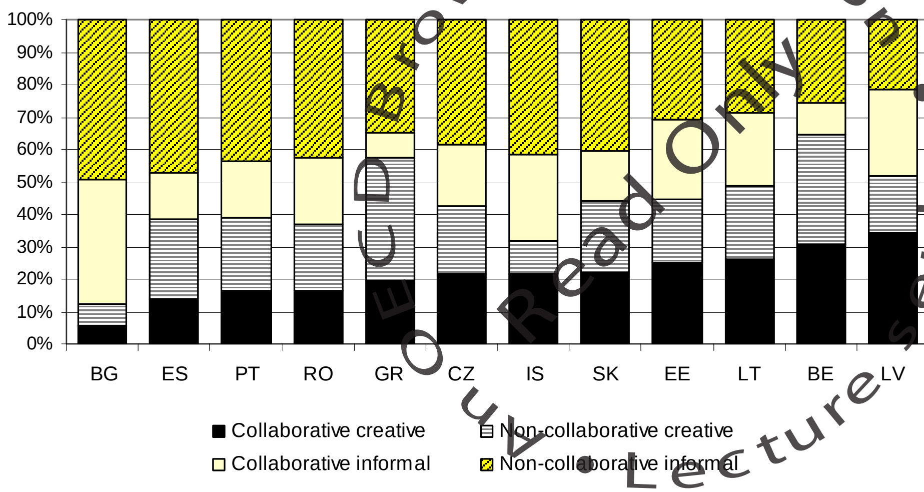
Figure 4.3. Innovative firms' methods of innovation, by country



Source: CIS3 micro-aggregated data referring to innovation activities in 1998–2000.

4.4. Conclusion

This chapter contends that one of the main barriers to the use of the CIS by the policy community is a lack of indicators and analyses that are relevant to policy needs. In part, this is unsurprising, because one of the main goals of the CIS is to provide data on non-R&D-based innovation activities, whereas supply-side R&D support programs dominate innovation policy. The growing policy interest in demand, commercialization and collaboration should enhance the value of the CIS, but this also requires using the CIS data to develop appropriate indicators on these issues. The academic community could also help by discussing the policy relevance of their research.

One of the main problems to date is poor links between the policy community and statistical offices and academics that use the CIS data. One respondent to the UNU-MERIT interviews noted that analysis "must be pull driven – pulled by policy interest and not the other way around. Without these interface mechanisms, the analytical results of the CIS are not visible." According to a second respondent, the results of the CIS are rarely used to inform policy because of the "long, long distance between the people who write papers based on the CIS and the decision-making level at ministries."

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The three examples of new types of indicators that could be created using CIS data are a response to suggestions made by the policy analysts interviewed by UNU-MERIT. However, this is an ad hoc and incomplete method of identifying the types of indicators that would be of use to the policy community. In this respect, Statistics Canada offers a good example of the right approach. The division responsible for the Canadian Survey of Innovation is frequently in contact with its users in government ministries and can provide customized analyses of data or implement additional surveys, based on funding by the ministry making the request. This process ensures that Statistics Canada has ongoing interaction with the users of innovation data and the in-house expertise to respond to their needs.

Fortunately, there are several initiatives underway to improve available indicators based on the CIS and to solve some of the problems with micro-economic analysis. The OECD, Eurostat and the group of Nordic countries are currently supporting research on the development of new CIS indicators. The OECD is also organizing a series of parallel econometric analyses of national innovation survey data in order to overcome limited access to data from more than one country. By the spring of 2007, over 15 countries were participating. This initiative should provide more robust results on major policy issues, such as the link between innovation and productivity. Eurostat is also developing a "safe access centre" to permit academic access to CIS data from several European countries.

Finally, Europe's industrial structure, with large fixed investment in low- and medium-technology sectors, means that the goal of a marked growth in productivity over the short term cannot be attained without a significant increase in the innovative capacity of firms active in low- and medium-technology manufacturing sectors and the service sectors. Diffusion-based innovation has a strong influence in these sectors, whereas R&D-based innovation is more crucial to high-technology manufacturing. The CIS was designed to provide data on many types of innovation activities and consequently should be a key source of useful data for the European policy community on knowledge diffusion, collaboration and other areas of interest to policy. These indicators need to be provided for both R&D performing and non-R&D performing firms.

Acknowledgements

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Chapter 5

CAPTURING DESIGN: LESSONS FROM THE UNITED KINGDOM AND CANADA

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5.1. Introduction

The essence of innovation is the process of bringing to market new products or processes, which, if successful, generate new economic value. Traditionally, this process has come to be viewed as one in which the primary inputs are scientific, technological or commercial. Scientists working in university, corporate or public laboratories generate new knowledge in a variety of forms that may lead to commercializable outputs. Institutions of higher learning produce highly qualified personnel, who transmit knowledge in embodied form throughout the economy, enhancing the innovative capacity of firms. Engineers, technical workers and organizational specialists develop new production processes and improvements to existing processes. Interaction with customers and suppliers provides important knowledge inputs that further contribute to the innovation process.

However, there is an emerging consensus that innovation does not simply occur in the realm of scientific discovery. It is not the result of research and development (R&D) activities alone, and it is not necessarily associated with a particular technology. Rather, innovation takes place throughout the economy and rests on a variety of inputs, including non-technological activities. Scholars and policy makers now recognize the critical role of non-technological innovations in the creation of economic value and the competitiveness of firms, regions and nations. Yet, measurement of innovation activity rests heavily on traditional technology-based indicators, such as R&D and patent activity. In fact, these measures have been the lifeblood of national statistical agencies and other organizations responsible for capturing the importance of innovation to economic growth

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and productivity. Design is increasingly viewed as a key aspect of the innovation process, and investment in design is one of the most important assets for businesses and nations. In the United Kingdom, design use is captured through the Community Innovation Survey (CIS); however, there remains little systematic evidence of how Canadian firms, for example, are using design. Given the significant role of design in innovation and the failure of the traditional approach to measuring innovation activity to capture it, it is crucial to ask: How can the role and significance of design in the creation of economic value be captured and measured?

This chapter addresses this question by reviewing the accumulated evidence – both quantitative and qualitative – of the importance of design as a key input in the innovation process and as a source of value added in a wide range of sectors, and by suggesting some strategies for modifying innovation surveys to capture the role of design in the innovation process.

5.2. Why is design a critical input in the innovation process?

The literature on innovation has traditionally focused on the role of universities and laboratories, patenting, and scientific and technological R&D. However, design is an important and often overlooked aspect in the process of firm learning and innovation. The argument presented here for incorporating design into the measurement of innovation is consonant with recent literature on creativity and the emerging cultural economy, as well as with literature on the business use of design. Together, these provide some theoretical insight into why design requires attention in the study – and measurement – of innovation and the innovative capacity of firms, industries, regions and nations.

5.2.1. Creativity and the cultural economy

A well-established literature in the social sciences now recognizes that creative, symbolic and aesthetic content and inputs are critical in the production of goods and services in the contemporary economy (Lash and Urry 1994; Scott 2001). Within this literature there are two focal points. The first of these documents the specific industrial dynamics of a set of creative and cultural industries, including film and television, new media, fashion, publishing, music and advertising (see Scott 2001; Power and Scott 2004). Studies consistently demonstrate that firms in these creative and cultural industries are often highly innovative, yet their innovative capabilities rely less on scientific discovery and R&D in the traditional sense and more on a variety of other inputs, including artistic and design inputs. The second point, while recognizing that the creative and cultural industries are themselves important sources of innovative products and can enhance the innovative

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capacity of other industries, emphasizes the role of highly skilled, creative workers in the innovation process. Creative workers are critical to the economic performance of firms and regions through their roles in creating new products and processes and engaging in creative problem-solving (Florida 2002; Markusen, Schrock and Cameron 2004). This suggests that creative inputs (such as design) can be applied in a number of different business and industrial contexts extending beyond the creative and cultural industries.

5.2.2. The business use of design

As noted above, it is now widely accepted that creative inputs are critical in the production of goods and services. Lash and Urry (1994, 15) claim that "the design component comprises an increasing component of the value of goods," resulting in the centrality of the design process and the increasing "design intensity" of products and services across the economy. In other words, design must be understood as a strategic resource used to enhance firms' competitiveness (Power 2004). Recent literature on the "business of design" echoes this sentiment (Nussbaum 2004a). In fact, the phenomenal market success of products such as Apple's iPod and other electronics made by companies such as Sony, LG and Samsung is widely attributed to the companies' ability to use design effectively throughout their business strategies (Nussbaum 2004b, 2005). However, it is not just technology-intensive industries that have used design to secure their position in the global marketplace. Firms in more traditional industries, such as furniture, textiles and apparel, have also been able to reinvent themselves through the effective use of design (Lorenzen 1998; Rantisi 2002; Leslie and Reimer 2003).

Within the firm, design can be incorporated throughout the research and product development phase, applied to manufacturing processes to reduce costs, and used in the creation of retail environments and in branding, packaging and marketing, enabling firms to differentiate their products and services in local and global markets. Firms can take advantage of design capabilities by *a)* having their own in-house design department; *b)* employing designers as part of multidisciplinary teams in various facets of their business (*e.g.* concurrent engineering, product development, marketing); *c)* hiring freelance designers to work on specific projects; *d)* purchasing the services of an outside design consultancy; or *e)* using some combination of the above four options.

While the discussion above identifies design as critical to the innovation process, only recently have studies explicitly documented this relationship. Most of the evidence concerning the effective use of design to fuel innovation and ultimately secure value added for a firm has emerged from Europe and a

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handful of other developed and developing countries and relies on individual cases studies or one-off surveys (New Zealand Institute of Economic Research 2003; Power 2004; Danish Design Centre 2003; Design Council 2004; New Zealand Design Taskforce 2003; DIAC 2004; Gertler and Vinodrai 2004). Overall, these studies suggest that design is a critically important source of economic value, raising levels of profitability, productivity and competitiveness. The use of design can enhance sales by improving both the functional and aesthetic qualities of a product. It can also reduce production costs, simplify and enhance the sustainability of the production process, and differentiate, brand and add value to products in the market.

Despite the accumulated empirical evidence that design is an important input in the innovation process, there are few systematic studies that provide comprehensive data on the use of design across national economies. Furthermore, there is a lack both of a common definition of design and of systematic indicators of design in innovation even at the national level, making reliable national comparisons and international benchmarking difficult (Bessant, Whyte and Neely 2005; Haskel *et al.* 2005; Swann and Birke 2005; Tether 2005). This oversight can, in part, be attributed to the lack of design-related questions in the survey instruments used to capture innovation.

Most innovation surveys rely on the *Oslo Manual*, which provides guidance on data collection for a comprehensive set of innovation indicators. The current edition of the *Oslo Manual* (OECD/Eurostat 2005) provides a definition of innovation that extends beyond the development or use of various technologies. Its concept of innovation includes organizational and marketing innovation alongside established forms of product and process innovation. Yet, even with these promising revisions, the *Oslo Manual* includes only a limited treatment of design and remains heavily biased towards production and manufacturing activity. For example, design is included as an example of marketing innovation, which suggests that design is conceived only as a decorative add-on. Design is not included as a separate innovation activity or expenditure category in the *Oslo Manual*'s recommendations for coverage in innovation surveys.

Surveys in New Zealand and the United Kingdom, however, have identified design as a separate input in the innovation process. For example, elsewhere in this volume Fabling uses innovation survey data from New Zealand to show that there is a positive and significant relationship between innovation and design use.

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5.3. Challenges in measuring the contribution of design to innovation

This section examines the measurement of design in the United Kingdom and Canada. These case studies offer stark contrasts in how design has been incorporated into the measurement of non-technological innovation in these countries. They also provide lessons for analysts and policy makers on future directions for the incorporation of the use of design into the understanding and analysis of innovation processes and outcomes.

5.3.1. Design and innovation: evidence from the United Kingdom

The United Kingdom has a long-standing and active design promotion policy, and its Design Council is charged with promoting good design practice to facilitate competitiveness and innovation among UK firms. Design has traditionally been perceived in the United Kingdom as an important source of comparative advantage, and recent evidence has shown that the use of design among UK firms improves business performance and productivity (DTI 2005; Design Council 2004). However, these strengths are often underutilized, and design has not been prominent in UK innovation policies.

Within the UK context, there are two primary sources of data on the business use of design. First, the Design Council has conducted a series of landmark surveys and studies (see, for example, Design Council 2004). Second, the UK Innovation Survey (UKIS), carried out as part of the CIS, includes a small number of questions directly related to the use of design in the innovation process. Like other innovation surveys, the UKIS records the importance that firms attach to design-related intellectual property (IP), including design registration and complexity. However, in contrast to the prevailing approaches to measuring innovation that follow the *Oslo Manual*, the UKIS collects information on design expenditure as a distinct innovation input. Using these data, it is possible to develop design-related indicators that can be linked directly to measures of product and process innovation. This permits a rigorous analysis of how design-related innovation activities relate to other factors in the innovation process.

Results from the UKIS 2005, part of the fourth CIS (CIS4), provide some interesting insights into firms' use of design. While more businesses identified in-house R&D (32%) or capital expenditures (47%) as important inputs, 19% of firms identified investments in design as important to their innovation activities. Furthermore, spending on design accounted for 5% of total firm expenditures on innovation. While this was only a modest proportion of overall expenditures, it was higher than firms' expenditures on acquiring external sources of knowledge (4%), an area that receives significant attention from policy makers and academics alike. Moreover, the

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propensity to invest in design did not vary significantly across industrial sectors, with a similar proportion of firms in knowledge-intensive services, manufacturing and retail reporting design-related activity. This provides some preliminary evidence that design is an important factor in innovation across the UK economy.

However, there were a number of other design-related expenditures that could not be measured directly, since some design activities were included in other categories within the UKIS. For example, the experimental development component of R&D can include design activity. In addition, when respondents were asked to estimate their design expenditures, they were instructed to exclude any spending already accounted for in their R&D expenditures. Similarly, preparing innovations for the market accounted for a high proportion of total firm expenditures on innovation, and this activity probably included expenditures on new packaging and presentation, which are design-intensive activities.

Despite this incomplete coverage, the differences in the propensity to innovate between firms that were "design-led" and those that were "technology-led" can be examined. Design-led firms were those that either had design expenditures or used design registration or complexity to protect their innovations. Firms that engaged in R&D activity (inside or outside the firm) or assigned some importance to patents to protect their innovations were considered to be technology-led. Of course, there was substantial overlap between these two categories. Table 5.1 shows that the majority of technology-led firms were also design users. Firms that were both technology- and design-led were considered to be "design-inclusive."

Table 5.1. Overlap between design- and technology-led firms

	Not design-led	Design-led	Total
Not technology-led	59.5%	7.3%	66.8%
Technology-led	9.2%	24.0%	33.2%
Total	**68.7%**	**31.3%**	**100.0%**

Source: UKIS 2005 (CIS4) (authors' calculations).

Did firms that were design-led or design-inclusive have higher levels of innovation than technology-led firms? Figure 5.1 shows the propensity of firms in all three categories to innovate. While there was little difference in propensity to innovate between firms that were only design-led or technology-led, firms with complementary technological and design-related investment (design-inclusive) had a greater propensity to innovate.

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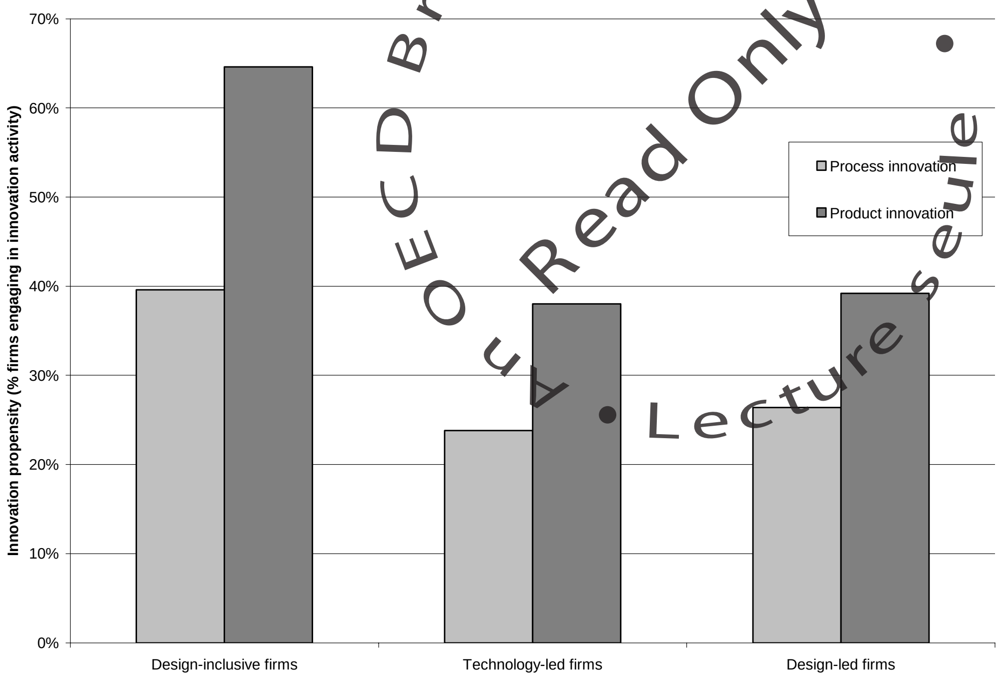
Figure 5.1. Propensity of firms in the United Kingdom to innovate, by mode of innovation



Source: UKIS 2005 (CIS4) (authors' calculations).

These complementarities can be assessed in greater depth by an examination of two conditional probabilities: the probability that a business will engage in a particular innovation-related activity (A) given that it engages in another innovation-related activity (B); and the probability that it will engage in B given that it engages in A. In general, these two probabilities will not be the same.

Table 5.2 summarizes these two conditional probabilities and shows the large number of one-way complementarities that existed between different innovation activities. A conditional probability of greater than 50% implies that the two activities complemented one another. For example, among firms that engaged in design-related activities, 71% were also involved in intramural R&D, 81% had capital and software expenditures, 76% invested in innovation-related training and 63% had marketing expenditures. However, the probability that a firm with other innovation inputs would engage in design was quite low. Overall, these findings reveal that engaging in design

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activity will lead firms to undertake other innovation activities, but the reverse is not necessarily true.

Table 5.2. Conditional probabilities of engaging in innovation-related activities

Innovation activity	Intramural R&D	Extra-mural R&D	Capital and software expenditures	External knowledge	Training	Design	Marketing
Intramural R&D	--	31%	73%*	28%	68%*	39%	51%*
Extramural R&D	82%*	--	82%*	45%	73%*	49%	60%*
Capital and software expenditures	45%	19%	--	25%	67%*	28%	39%
External knowledge	59%*	36%	85%*	--	81%*	43%	57%*
Training	49%	20%	77%*	27%	--	30%	45%
Design	71%*	33%	81%*	37%	76%*	--	63%*
Marketing	60%*	27%	74%*	31%	74%*	42%	--

* Indicates probability greater than 50%.

Source: UKIS 2005 (CIS4) (authors' calculations).

By moving beyond simple bivariate analysis and employing econometric modeling techniques, it is possible to examine the extent to which design influences innovation outcomes while controlling for the effects of other innovation inputs and other conditions of the innovation system. A series of experimental probit regressions was conducted using three different measures of the propensity to innovate as the binary dependent variable: the introduction of a product innovation (a good or service that was at least new to the firm), a process innovation, and a novel product innovation (a good or service that was new to the market). While the full analysis included variables to account for the different sources of information that respondent firms drew on in the innovation process, alongside control variables for industrial sector and region, Table 5.3 reports only the estimated parameter values for the marginal effects of a firm employing the specified innovation inputs, together with tests of significance – standard errors and z-scores.

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Table 5.3. Determinants of innovation: probit regression results

	Product innovation			Process innovation			Novel product innovation		
Independent variables	**dF/dx**	**Std. error**	**z-score**	**dF/dx**	**Std. error**	**z-score**	**dF/dx**	**Std. error**	**z-score**
Intramural R&D	0.170	0.010	17.25	0.055	0.008	7.6	0.138	0.018	7.3
Extramural R&D	0.037	0.012	3.04	0.036	0.009	4.2	0.054	0.019	2.8
Capital and software expenditures	0.039	0.009	4.24	0.122	0.007	17.3	-0.051	0.019	-2.6
External knowledge	0.034	0.011	3.02	0.015	0.008	1.9	0.027	0.019	1.4
Training for innovation	0.036	0.009	3.93	0.062	0.007	9.0	-0.010	0.018	-0.6
Design functions	0.059	0.011	5.46	0.033	0.008	4.3	0.071	0.018	3.9
Market preparations	0.189	0.011	18.67	0.043	0.007	6.1	0.124	0.017	7.2

Source: UKIS 2005 (CIS4) (authors' calculations).

In all three versions of the model, investment in design is positive and statistically significant. However, the relative importance of design in influencing the propensity to innovate depends on the type of innovation outcome. For example, in the case of product innovation, intramural R&D and market preparations had a larger impact than design. With regard to process innovation, design had a lower parameter value than in the case of product innovation, and capital and software expenditures had a greater impact than design. Finally, in the case of novel product innovation, design had a higher marginal effect and was relatively more important than in the other two cases, while some other inputs had a negative impact or were not significant. For example, the acquisition of external knowledge, the subject of much policy activity in many countries, did not appear significant in the introduction of novel product innovations.

Overall, the results of this analysis suggest that engaging in design is associated with significantly higher probabilities of firm-level innovation. In statistical terms, this translates into a 15–20% increase in the propensity to innovate compared with firms that do not report distinct design-related investments in the innovation process.

5.3.1. Design and innovation: evidence from Canada

In Canada, design has not been particularly prominent within cultural or economic policy, nor has it been systematically targeted as a source of innovation for Canadian firms.[1] However, recent research has begun to fill this gap in our understanding of the contribution of design in the Canadian context (Gertler and Vinodrai 2004; Vinodrai 2005, 2006; see also DIAC 2004). For example, Gertler and Vinodrai (2004) have studied the contributions that design skills make within a wide range of established and emerging sectors. Figure 5.2 shows that the growth of Canada's design labour force (defined occupationally to include industrial, interior, graphic, fashion, theatre and other designers, as well as architects and landscape architects) outpaced that of the overall labour force between 1987 and 2002.[2] Canada's design workforce grew at a rate of 3.7% per year, compared with only 1.7% for the overall labour force. Figure 5.3 compares employment in design occupations with employment in Canada's design *industry* between 1987 and 2002. It shows that, overall, employment in the design workforce (defined occupationally) grew at a faster rate than employment in the design industry, suggesting that industries outside the design industry were availing themselves of design-related expertise by employing designers *directly*. Figure 5.4 confirms this finding by showing the sectoral distribution of people working in design occupations in 2001. Fewer than half of all designers worked in specialized design firms found in professional services. In other words, designers were employed in a wide range of traditional and emerging industries.

1. It is worth noting that, in contrast to most Canadian jurisdictions, Montreal and the province of Quebec have successfully incorporated design into their economic development strategies (Leslie and Rantisi 2006). In Ontario, design has only recently been acknowledged as an important source of innovation and value added (Design Exchange 1995; DIAC 2004; City of Toronto 2006).

2. While the analysis presented in Gertler and Vinodrai (2004) uses data for Ontario, this chapter offers a similar analysis conducted at the national level. In general, the results are quite similar.

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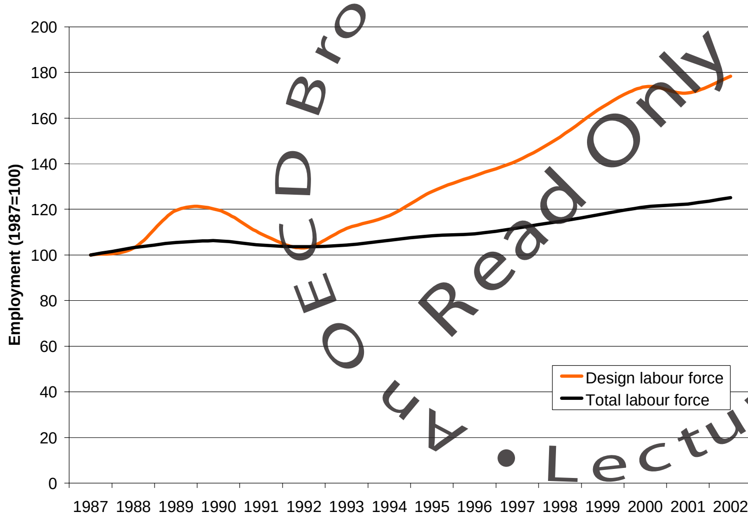
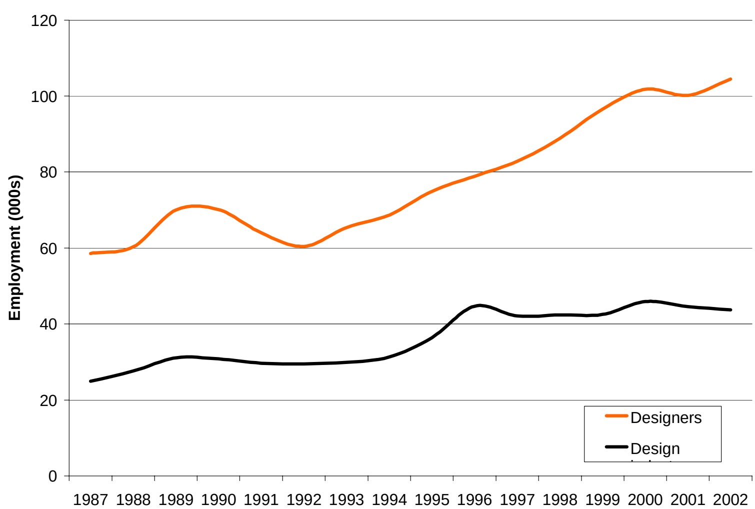
Figure 5.2. Indexed design employment in Canada, 1987-2002



Source: Statistics Canada, Labour Force Survey, 1987–2002 (custom tabulations).

Figure 5.3. Employment in design occupations vs. employment in Canada's design industry, 1987-2002



Source: Statistics Canada, Labour Force Survey, 1987–2002 (custom tabulations).

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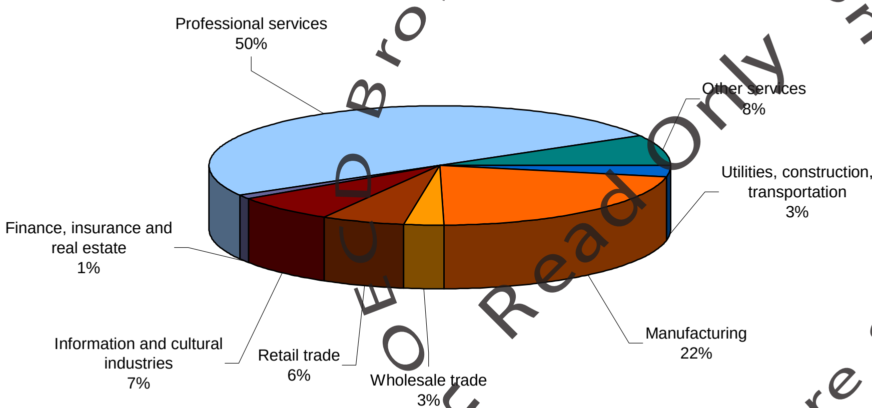
Figure 5.4. Sectoral distribution of designers in Canada, 2001



Source: Statistics Canada, Census of Population 2001 (authors' calculations).

The importance of this finding is emphasized elsewhere. Vinodrai's research (2005, 2006) explores how design expertise is transferred between the design industry and other sectors of the economy. Through an analysis of employment dynamics, contractual relationships, freelance activity, and the longitudinal labour market mobility of industrial and graphic designers, she demonstrates how designers work in various settings over the course of their careers, both in the design industry and in other industries. Overall, the findings from Vinodrai's analysis (2005) have led her to conclude that design expertise and knowledge developed in working for a variety of employers can be transferred between firms and industrial sectors via labour market mobility. Firms benefit from designers' circulation in the labour market, since designers can bring new knowledge into the firm, thereby acting as an important source of embodied knowledge, in much the same way as engineers, scientific researchers and technical workers (see also Angel 1991; Almeida and Kogut 1999; Henry and Pinch 2000).

The empirical findings reviewed above suggest that Canadian firms in many industries are hiring designers and that this practice has become more widespread in recent years. However, it remains an open question as to how *effectively* Canadian firms are using design expertise. It is also imperative to differentiate between users and non-users of design to determine if some firms and/or industrial sectors have made more extensive and effective use of design, as well as how and where design expertise is being utilized and applied within firms.

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Unlike the situation in the United Kingdom, there are few comprehensive data sources in Canada that explore the various aspects of design or that attempt to understand the business use of design. The quantitative analysis presented above relies on data from Statistics Canada's Census of Population and Labour Force Survey (Gertler and Vinodrai 2004). These data sources enable analysts to understand the socio-economic and demographic characteristics of people working in design occupations or in the design industry. However, they do not provide information about the industrial dynamics of these sectors, nor do they focus on how design is being utilized within particular industries. Furthermore, these data are cross-sectional and therefore tell very little about employment mobility and other factors that can be revealed through longitudinal analysis. Vinodrai's analysis (2005, 2006) relies on a qualitative methodology to understand the longitudinal labour market dynamics of designers.

The only comprehensive, national survey that explicitly examines the business of design in Canada is the Survey of Service Industries: Specialized Design, which has been conducted annually since 1998 (Statistics Canada 2007). This survey is based on a sample of establishments in the specialized design services industry, which includes: landscape architectural services; interior design services; industrial design services; graphic design services; and other specialized design services.[3] The survey provides basic information about the number of establishments, their size and their sources of revenue (design consultation, design services, project management, other), as well as some broad-brush information about the types of clients (government, businesses, individuals and/or families) and where these clients are located (same province, different province, international).

However, there are a number of drawbacks to the survey. First, there is no detailed geography of the design services establishments below the provincial level. Given that design employment tends to cluster in metropolitan areas, this is a significant shortcoming. Second, there is very limited information about the clients and users of design services, including their industrial or sectoral classification and the nature of the relationships between design service providers and design users. Hence, leading and lagging sectors in the use of design services cannot be identified. Third, the survey fails to capture in-house design activities within non-design firms. Given the evidence that this activity has been increasing in relative and

3. Statistics Canada was able to identify readily establishments in the specialized design services industry only with the adoption of the 1997 North American Industry Classification System (NAICS). Prior to this, the Standard Industrial Classification (SIC) did not allow for the easy identification of firms in the design services. Architectural firms are covered under a separate survey: the annual Survey of Architectural Services (Statistics Canada 2006a).

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absolute terms in recent years – borne out by the key finding that roughly half of all designers do not work in design firms – this too is a critical gap in the understanding of design use in the economy. Finally, there are few direct ways to assess the business practices and innovation performance of firms in the design services industry, and to link these to their economic performance.

Statistics Canada's Survey of Innovation solicits information about product and process innovation in manufacturing, natural resources and specialized services firms. In fact, the sample for the Survey of Innovation 2003 (Statistics Canada 2004) included establishments in the industrial design services industry. While including this industry in the survey had the advantage of revealing the sources of innovative ideas and the level of innovation for establishments in one part of the design industry, it did not capture how design was being used in other industries.

The Survey of Innovation gathers useful data on the sources of information for innovation activities, both internal and external to the firm.[4] There is, however, no explicit recognition of the role that designers (in-house or from outside the firm) play in enhancing the innovative potential of a firm. Furthermore, while the Survey of Innovation links innovation activity to firm performance (measured in terms of sales revenues, quality, process improvements, productivity and market share, *inter alia*), it does not shed light on the impact of design inputs on firm performance. In other words, it leaves unaddressed a key question: How does design add value to firms' products and services and enhance firms' competitive success?

Despite these shortcomings, the Survey of Innovation has considerable potential as a tool for addressing such questions. Perhaps its most important characteristic is the breadth of its target population, since it covers a wide range of sectors in the Canadian economy.[5] It includes both newer and older industries, and incorporates both more and less knowledge-intensive forms of economic activity. Such a sample structure would support an analysis of

4. For the Survey of Innovation 2005 (Statistics Canada 2006b), the internal sources of information included: R&D staff; sales and marketing staff; production staff; management staff; and other plants or R&D laboratories in the same firm. External sources included: suppliers; clients or customers; competitors; consultants; commercial, public or non-profit R&D laboratories; universities and colleges; conferences and trade fairs; scientific journals and trade publications; investors; industry associations; the Internet; and experienced entrepreneurs.

5. Each of the past Surveys of Innovation has targeted a slightly different sample. The Survey of Innovation 1999 (Statistics Canada 2001) covered approximately 6 000 businesses in the manufacturing, construction and natural resources sectors, while the Survey of Innovation 2003 focused on approximately 1 700 establishments in specialized services (including industrial design). The Survey of Innovation 2005 returned to the broader coverage of the 1999 survey, with a sample of approximately 8 000 firms.

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how the use of design varies by sector, firm size and other pertinent characteristics.

A small number of new questions could be added to the Survey of Innovation to measure the *prevalence* of design use. They would gather information on:

- The number of full- and part-time, as well as permanent and contract, design staff employed in-house;[6] and
- The use of designers external to a firm (freelancers, design firms), measured in terms of the dollar value of expenditures to purchase their design services.

Relatively modest, incremental modifications to existing Survey of Innovation questions[7] would allow the collection of vital information concerning the *importance* of designers in contributing to innovative ideas, by gauging:

- The importance of design staff in-house in generating innovations; and
- The importance of external design firms and freelancers in generating innovations.

More probing analyses exploring *how* design contributes to the innovation process would require new questions, such as:

- At what stage in the innovation/production process is design used:
  - initial stage of product/process development;
  - later stage (*e.g.* customization);
  - packaging, marketing?

Additional questions could explore the link between design activity, innovative capacity and firm performance more explicitly. For example, a national study in the United Kingdom commissioned by the Design Council (2004) asked firms across the economy a number of questions related to the use of design within their firm:

6. This could be further disaggregated by type of designer, using accepted occupational categories such as industrial, interior, graphic and fashion designer, architect, landscape architect, and other.

7. Question 25 in the Survey of Innovation 2005 asks: "During the three years, 2002 to 2004, how important to your plant's innovation activities were each of the following information sources?"

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- How have design, innovation and creativity contributed to your business over the last three years?
- Has design become more important in maintaining your competitive edge over the past 10 years?
- What role does design play in your business?
- How is design used in new product or service development?
- What are your main reasons for not using more external design expertise?

5.4. Learning from the United Kingdom and Canada

This chapter has reviewed the accumulated arguments, both conceptual and empirical, concerning the growing importance of design as a determinant of firms' innovative capacity and competitive success. It is clear from this review that the economies of countries in the Organisation for Economic Co-operation and Development (OECD) are becoming increasingly reliant on the use of design as a way to enhance the market success of goods and services. As part of the more general trend towards identifying and exploiting non-price forms of competition, firms in many of these countries appear to be discovering the importance of design as a source of economic value.

While some countries – most notably, the United Kingdom and countries in Northern Europe – have led the way in devising means to document this phenomenon statistically, Canada and other OECD countries have not kept pace. This chapter's exploratory analysis of the Canadian case, using available employment data reported by occupation and industry, as well as more qualitative information, appears to indicate that design activity is expanding rapidly in Canada, and that it is spreading well beyond the design industry itself. This is in keeping with evidence from other OECD countries (Danish Design Centre 2003; Power 2004). Yet, the current national surveys of innovation do not collect information on a systematic basis that would allow the documentation of the prevalence of design use and its importance to the innovation process in sectors across the OECD economies. Moreover, the current approaches to documenting the structure of and interrelationships between elements within most national innovation systems are hampered by an unduly restrictive list of participants: designers are conspicuous by their absence from the list of agents of innovation and sources of innovative ideas.

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Given this mounting evidence, it is clear that the existing panoply of indicators of innovation activity needs to be modified to capture the growing importance of designers and design inputs to the innovation process. In other words, those actors who are responsible for providing design inputs need to be counted among the usual list of agents – scientists, engineers, managers, technical/skilled workers, university and private researchers, consultants, customers and competitors – who are routinely regarded as active participants in the innovation system. How, then, can the extent and impact of design's contribution to the innovativeness and competitive success of firms be measured? How can the ways in which firms are integrating design into their innovation and production practices be assessed?

The review of the UK evidence indicates some promising directions. The survey instruments and questions developed for the UKIS and by the Design Council offer some important correctives to the measurement of innovation activity that account for the role of design. Clearly, adding questions similar to those used by UK researchers incrementally to existing surveys of innovation (without the offsetting deletion of other survey questions) increases the risk of adding unduly to firms' burden of response. Nevertheless, the growing body of international evidence concerning the strategic importance of design across the economy warrants a serious reconsideration of the content and structure of innovation surveys in order to reflect these recent developments. Furthermore, the linkage of innovation survey data to other measures of firm characteristics and performance, including those collected through other establishment-based surveys, could allow the determination of the extent to which a firm's use of design is correlated with export activity, growth in sales, employment and market share, and other key performance outcomes.

If the secular trends documented in this chapter are indeed as fundamental and widespread as they appear to be, then it is of critical importance for high-wage, developed economies such as the OECD countries to collect information on design use and its role in innovation. This chapter has argued that a number of modest but significant incremental modifications to existing national innovation surveys would go a long way towards achieving this goal, while also complementing the useful information already available through other national surveys and official statistical data sources, such as national censuses. Given the growing recognition of non-technological sources of innovation, such as design, this would seem to be a good time to initiate a rethinking – and redesign – of existing data collection instruments.

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Chapter 6

ENRICHING THE INDICATOR BASE FOR THE ECONOMICS OF KNOWLEDGE

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6.1. Introduction

This chapter addresses the issue of the development of indicators aimed at providing a measurement base with both breadth and depth from which research in the "economics of knowledge" can benefit. While initial attempts at quantification in the area of the knowledge economy were based on both national accounting (Machlup 1962) and growth accounting (Abramovitz and David 2001), the use of indicators with a direct bearing on knowledge (Jaffe and Trajtenberg 2002) is becoming the dominant approach. There is no summation (or composite value), as in accounting, but rather a collection of available statistics on several dimensions of knowledge, such as scientific and technological knowledge, innovation inputs and outputs, and organizational practices.[1] The strength of this latter approach is that, depending on the quality of the indicators, it allows a genuine grasp of the phenomena of knowledge and innovation under consideration.

The economics of knowledge is now at the point where it has the potential to become a strong, empirically disciplined science, depending on whether enough progress can be made on developing the underlying data and the indicators ensuing from them. This chapter argues that the economics of knowledge is at a crossroads, and it uses the development of knowledge management indicators as an illustration of this.

1. See Godin (2007) for the development of this classification with regard to different approaches to "measuring knowledge."

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6.2. The history of knowledge management indicators

Knowledge management (KM) is generally considered as a set of new organizational practices that seems to be of broad relevance to the knowledge economy. It covers any set of practices or processes intentionally designed to optimize the use of knowledge – that is, to increase efficiency of allocation in the areas of knowledge production, distribution and use.

When some statisticians, economists and analysts started to become interested in studying KM, information about it consisted mainly of anecdotal evidence, success stories and a few business studies done by consulting companies. Following are accounts of a couple of successful initiatives that first started to attract attention through publication in business journal articles and in such influential books as *Working Knowledge* (Davenport and Prusak 1998, xiv):

> At Hoffman-LaRoche a knowledge management initiative in 1993–1994 reformed the process of developing new drug applications, the voluminous, complex documents that must be submitted to the FDA [Food and Drug Administration] before any new drug can be approved and brought to market. In significant measure because of the initiative, applications and approval for several new products now take many months less than the usual time to complete, at a saving of $1 million per day.
>
> At Hewlett-Packard, the amount of product knowledge required to effectively use and support complex computer products has exploded. So in 1995, the company implemented a knowledge management tool called "case-based reasoning" to capture technical support knowledge and make it available to personnel around the world.

In their introduction, Davenport and Prusak claim that KM is a great source of competitive advantage, enhancing both the efficient allocation of this precious resource and companies' innovative capabilities. There is no way of knowing if they are right. However, consultants and gurus are quick to claim that KM is the unique solution to all problems encountered in the course of a firm's daily operations.[2]

Economists usually like to know a bit more than this about a new practice or technology that starts to be widely diffused in the economy. Since many firms are spending money on KM, one would expect them to be getting something in return. But spending money on "something" is hardly a

2. This is not, of course, a reference to Davenport and Prusak, who have written a useful book that articulates their considerable knowledge, experience and practices in this area.

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reliable predictor of its returns. How do economists know if KM is more than a fashionable social technology when there is no evidence that implementing it is efficacious? Is KM simply a new managerial discourse used to renew motivation and commitment among participants in the capitalist enterprise (Boltanski and Chiapello 1999) or is it an effective organizational innovation that has the potential to increase labour productivity?

To answer these questions, economists have to design an applied research program that obviously involves the building of indicators (Foray 2004). The quest for broader and more systematic empirical information relating to KM entails a four-step process:

- Conceptualization: it is necessary to examine the literature to see whether there are economic reasons to manage knowledge. The idea is to search for and articulate stylized facts about knowledge as a commodity to see whether a good economic case can be made for a private company to invest in KM.
- Data collection: data to highlight the various dimensions of the phenomenon are needed. This is a crucial issue. A special feature of the economics of technical change, innovation and knowledge is that it calls for large amounts of data, much of which is rather unconventional for economists (Trajtenberg 1990). This feature reflects both objective econometric requirements and the conviction that, if the phenomena of knowledge and innovation are to be understood, the only choice is to seek data with a direct bearing on them. This is less obvious than it sounds: economists are reluctant to engage in raw data collection, trying instead to compensate for the scarcity of data with econometric ingenuity (incentives in the profession are set accordingly); the prevailing conception of legitimate economic data is rather narrow and conservative. This may be justifiable in other areas of economics, but not in the realm of innovation and technological knowledge.
- Answering the big question: does KM matter in economic terms? That is, would an increase in inputs and resources for KM lead to more outputs? Unless this question is answered, there is no point in proceeding to the final step.
- The manipulation of incentives and inputs to achieve particular goals – the usual prescription of economics (Griliches 1962).

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6.2.1. Stylized facts about knowledge as a commodity

Clearly, many views on knowledge as a commodity can be found in the literature. Several of these can be used to build an economic case for implementing KM practices.

Knowledge is a product of learning by doing: Many innovation activities occur "on the floor" or on-line (as opposed to off-line), through the mechanism of learning by doing. In this process, innovation is not the main goal, but may nevertheless occur as a joint product of the activity. The process can even entail an experimental approach (people plan experiments on-line and draw conclusions, new options are generated and variety ensues). However, since the main goal is to deliver a service or produce a good at the end of the day, the learning process can conflict with a worker's normal expected performance. Thus, there is a role here for KM in the organization of proper conditions to manage this conflict and to promote experimental learning in the daily operational context of a manufacturing plant or service operation.

Knowledge is like a fixed cost: A piece of knowledge needs to be produced only once and can be used repeatedly by as many people as want to use it. The production of knowledge is like a fixed cost in the production of goods and services. Fixed costs are by definition a source of economies of scale in production, which raises various strategic and policy issues. Again, an economic case can be made for KM, this time as a method for seeking some kind of optimal use of knowledge.

Knowledge needs to be reinforced: Evidence in the psychological literature shows that, when people are interrupted in the performance of a task, their ability to remember it is diminished. Hirsch (1952) found that, when a job was resumed after an interruption, it was at a lower level than that attained prior to the interruption. The knowledge derived from learning by doing quickly loses its value and, if the stock of knowledge is not replenished by continuous production, it depreciates rapidly. A case can be made here for KM as a method of organizing mechanisms explicitly to aid the memorization and maintenance of existing knowledge and to minimize accidental loss of inventions.

Knowledge is difficult to transfer: As von Hippel (1994) puts it, knowledge is "sticky." Stickiness raises a number of issues in terms of the organization of knowledge production and the integration of pieces of knowledge that have been produced in different places.

Knowledge is tacit: Typically, knowledge and expertise are neither articulated nor codified. Tacit knowledge resides in people, institutions or routines. The fact that it is tacit makes knowledge difficult to learn,

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memorize, recombine and transport. One solution, and this again makes an economic case for KM, is to codify knowledge: the knowledge is recorded on a medium. This entails high fixed costs, but all KM operations can then be performed at a very low marginal cost. Codification, as a KM procedure, increases the memory capacity of an organization and creates learning programs for new workers.

The last stylized fact found in the literature does not articulate any characteristic of knowledge as a commodity. Rather, it is the need for organizational structure and practices to complement the investment in information and communication technology (ICT). There is now considerable evidence that "organizational complements" – such as business processes, decision-making structures, incentive systems, human capital, corporate culture and KM – play an important role in a firm's ability to realize value from its ICT instruments (Brynjolfsson and Hitt 2005). The act of acquiring and maintaining these organizational complements is a real cost to the firm, but also a potential source of significant value when combined with appropriate investments in technology. KM practices appear to be an important organizational complement, playing a key role in increasing private and social returns from ICT investments. As Milgrom, Qian and Roberts (1991) put it, the deployment of ICT and the adoption of KM practices are mutually complementary, with each making the other more attractive. It is through the development of such complementary activities that the Solow paradox has been resolved.

Thus, there are plenty of economic motivations and arguments for private companies to design, implement and develop KM practices. The literature dealing with the main features of the economics of production and transmission of knowledge clearly builds an economic case for KM. It can be inferred from this that KM is probably more than just a managerial fashion; rather, it is a social technology that is likely to have a positive impact on efficiency, innovation and productivity. There are therefore grounds for proceeding to the next step, data collection.

6.2.2. Data collection

Good economic research depends on the generation of appropriate and reliable economic data. If economists want to comment on the economics of KM, the only way to do so is to have a measurement base on which research in the economics of KM and innovation can be founded. The Organisation for Economic Co-operation and Development (OECD) KM survey, the result of an intense collaboration between Statistics Canada and the OECD, was developed in 2001 and 2002 to:

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- Create a systematic database on the diffusion of KM practices in some OECD countries;
- Obtain some leverage in terms of international comparisons by using the OECD mechanism, which consisted of contracting with national offices to do the work within a common framework of statistical guidelines;
- Contribute to the stabilization/standardization of the conceptual categories and terminology of KM; and
- Create some infrastructural knowledge related to the survey (terminology, categories, questions, test results), so that more countries and researchers could use it to undertake further studies and analysis.

The survey, whose methodology, national studies and topics are extensively described in OECD (2003), produced important results. It demonstrated that it is possible to produce some aggregate measures of KM implementation and diffusion, and to build indicators of firms' behaviour with regard to KM; and it generated a series of results about the diffusion of KM, the effects of firm size and technology, firms' priorities in terms of KM practices and purposes (acquiring and sharing knowledge, human resource management, etc.), and the complementarities between KM and other innovation activities (see, in particular, Earl 2003, 2005; Earl and Gault 2003; Edler 2003; Kremp and Mairesse 2003; Lhuillery 2006).

6.2.3. Answering the big question

Is KM of significance in economic terms? The data have shown that KM practices are widely adopted within the private sector. However, there are plenty of cases of innovations in social technologies that have been extensively adopted over a short period, while no clear evidence about their economic impacts has ever been produced (Nelson 2003).

Kremp and Mairesse (2003) used French data from the third Community Innovation Survey (CIS3) to study whether there is a relationship between KM intensity and outputs (in either innovation or productivity). The evaluation of the economic impact of a new practice or technology is difficult, since the same firm cannot be observed simultaneously with and without KM. If a firm that has implemented some KM practices is studied, there is no direct way of discovering what the outcome would have been if the company had not implemented KM. There are several indirect approaches, however: for instance, one approach is based on the assumption that, as long as two groups of firms share the same characteristics, it is acceptable to compare the treated group (with KM) with the untreated group (without KM). Kremp and Mairesse, however, used the opportunity afforded by a very large dataset (6 000 firms) to search for statistically significant

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correlations between an indicator of KM intensity and output and outcome variables (innovation, patenting, labour productivity) in a cross-sectional econometric study. Their findings show the statistical and economic significance of the estimated impact of KM intensity (2003, 158): regardless of size, industry, involvement in research and development (R&D) and whether they belong to a group of firms, companies tend to innovate and patent more extensively if they have adopted KM policies. All else being equal, when KM intensity increases, the propensity to innovate, as well as innovation intensity, also increases significantly; the same is true for patenting. The estimated impacts are quite substantial and, in spite of all the usual reasons of econometric misspecification that potentially apply here, the authors claim that the results remain statistically informative. At a minimum, they reflect underlying positive correlations, conditional on a fair number of relevant factors. The authors' tests and results for the relation between KM intensity and labour productivity provide a similar picture of the positive effect of the new organizational practice on economic variables. As Kremp and Mairesse point out, all these results do not indicate causality, although such a causal link seems a priori more likely than not.

These results provide some detailed evidence for the view that intangibles like KM and other organizational complements are a crucial part of the explanation for the recent surge in productivity in OECD countries. They also encourage economists to extend the research towards incentive mechanisms and the social arrangements that would be most conducive to increasing KM intensity as an important driver of innovation and productivity.

6.2.4. Incentives

The fourth and last step in the process deals with the existence and identity of factors and incentives affecting the level of KM activities. It is instructive, for example, to consider the issue of employees who are encouraged, through some kind of rewards mechanism, to write, codify and share documents. These employees therefore have to undertake two different tasks (their normal work and the KM activity), and they have to choose a level of effort for each. The firm's challenge is to offer incentives to elicit the optimal level of effort. The theory of incentives in a multi-task setting claims that it is necessary to balance incentives optimally across tasks; otherwise, employees will inefficiently allocate greater effort to those tasks that offer them the highest return. On the basis of this general observation, it is possible to model optimal incentive structures for the effective implementation of KM practices.

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6.3. Market failures for indicators

The OECD survey provided the international economic and policy community with some useful results concerning KM:

- There is a strong economic case for implementing KM in private companies;
- The production of aggregate measures of various aspects of KM diffusion, as well as of firms' behaviour vis-à-vis the management of this asset, is possible;
- Some statistical tools have been tested and improved and are publicly available (Earl and Bordt 2003);
- The estimated impacts of KM on innovation and productivity are quite substantial; and
- It would be useful to proceed further towards the manipulation of incentives and inputs to achieve particular targets in terms of KM intensity.

However, the proof of concept – *i.e.* the demonstration that the questions are relevant and aggregate measures are possible – is by no means sufficient to ensure that new indicators are accepted internationally and the data collection is routinized.

As they exist now, the KM indicators (*i.e.* indicators of KM intensity) are by no means ideal. An ideal indicator has to pass successfully the tests of precision, absence of bias, stability over time, comparability across different classifications, resistance to manipulation, aggregation and cost (Jaffe 1999).

It is obvious that a new indicator will be improved if enough time is allowed for it to be used and tested, and for people to use it routinely for both data collection and data interpretation. While some indicators of R&D are now close to ideal (at least for those who believe in the importance of R&D in innovation and economic growth), the first attempts at R&D indicators required improvement.

This shows that the first phase of building and using a new indicator, which has demonstrated its relevance and some practical merits, is extremely perilous, often involving insurmountable obstacles. This is a selection phase, characterized by market failures that stem mostly from problems of "increasing returns":

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- The creation and initial use of an indicator entail high fixed costs (research, initial tests, survey design and implementation), which are difficult for a small group of initiators to bear;
- The wide diffusion of a new indicator requires strong network externalities: the more interesting the indicator and the higher the number of "users" (statistical offices), the greater the number of additional users it will attract;
- The successful implementation of a survey involves strategic complementarities at the institutional level among researchers, statisticians, policy makers and the business community, which exist only partially at the start (the section of the business community that has to be mobilized as a source of information about KM is different, for example, from that which provides information about R&D);
- There is a time series effect: "old indicators" create a double value for the corresponding survey done at time n – the value of collecting data at time n + the value of not discontinuing the time series; this second value is, of course, 0 in the case of a new indicator;
- Finally, a successful indicator is a "code," which enhances the efficiency of communication and information-processing procedures among a large number of economic agents. But a code represents an especially durable form of capital, and when individuals learn a code it is an act of irreversible investment on their part (Arrow 1974; David 1994). The need for codes that are mutually understandable within organizations causes individuals and groups to become specialized in the information that can be readily transmitted by the code and to ignore information that would require a different code to be absorbed. Since the code is part of the organization's capital, it will be modified only slowly over time.

All these features correspond to some form of increasing returns in the development and consolidation of new indicators. It is not necessarily the case that the international community will adopt an indicator, even if the proof of concept has been produced. As in any case of technological competition that entails uncertainty and increasing returns, the best will not necessarily win. The winners will be those that succeed in achieving enough momentum to benefit from the dynamic of increasing returns, while keeping other good candidates out of the market.

A further complication arises from a problem of scarce resources, which includes not only money, but also attention from policy makers (to interpret new indicators that might change their policy perspective) and time from the business community (to complete questionnaires). This means that a new indicator will often be imposed at the cost of existing ones. This creates

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more difficulties, since the existing indicators are somewhat closer to the ideal than the new one.

It is obvious that there is little room to correct these market failures. The initial phase of implementation is a decisive one. It should involve multiple interactions among researchers, statisticians and official survey administrators, policy makers and, of course, the business community as the source of information. This phase operates as a sort of filter through which very few new indicators pass successfully. Accounts of survivors of this phase show that success entails the creation of a coalition of stakeholders that rapidly recruits strategically valuable new members, a process resembling the creation and eventual domination of an "epistemic community."

6.4. Conclusion

The economics of innovation and technological knowledge is primarily an empirically disciplined science. The OECD KM survey, as well as many other examples relevant to this discussion,[3] shows the need for applied economists to learn and gather the facts of technology and organization themselves. Data based on remote proxies are inadequate. An ongoing challenge for applied economists in the area of innovation is to enlarge the scope of empirical material that economists will regard as legitimate, and perhaps even routine, in applied research. This effort is necessary if the economics of innovation and technological knowledge is not to remain purely abstract, but is able to link theory to practices. By doing this, it will be able to provide both private-sector managers and policy makers with information about the aggregate economic impacts of new organizational and human resource practices, new business methods and new discovery technologies.

However, the case of the development of KM indicators shows that this is a difficult process. The production of a proof of concept is no guarantee that the indicator under consideration will be adopted internationally in what has become the conventional manner. For example, there is no internationally accepted manual of KM indicators similar to the *Frascati Manual* (OECD 2002) for R&D indicators.

Nonetheless, KM practices, as systematically used by private firms, are clearly a central organizational concept in the knowledge economy, and it is therefore important to measure firms' behaviour in this area. In addition, KM and other new human resource practices are complementary investments that are larger than investments in ICT itself. However, they go

3. The measurement of user innovation is another case in point (see von Hippel elsewhere in this volume).

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largely uncalculated, and the task of measuring more effectively the intangibles that are increasingly important to knowledge-driven growth and firms' performance remains incomplete.

The challenge of developing a measurement base from which to study KM at the firm level is, therefore, still to be faced, and there is a need for stronger political commitment, as well as more interaction among statisticians, economists, policy makers and the business sector.

However, the great success of the development of indicators from firm-based surveys of innovation activity, as implemented in a number of European countries and elsewhere (including Canada), offers a reason for optimism. The success of the Community Innovation Survey (CIS) is easily explained. Innovation is an old and prestigious economic concept, familiar to economists (not only Schumpeterians). Little effort was required to attract the interest of policy makers, who were well aware of the importance of evidence about innovation performance, and it was equally easy to find the section of the business community in charge of innovation management in firms. Thus, the network of potential users was initially quite large and was strongly supported by powerful institutions. The strategic complementarities among the various stakeholders already existed, since they were quite similar to those for R&D data collection. Only the fixed cost of launching the survey could have been a problem, but this proved surmountable since a large number of institutions were willing to share the burden.

As part of this development, the most recent revision of the *Oslo Manual* (OECD/Eurostat 2005) – which is the "codebook" for innovation indicators – extends its coverage to new types of innovation, including "organizational innovation." This category is obviously broader than KM, but is clearly related to it. Most of the examples of organizational innovation in business practices are actually KM practices (OECD/Eurostat 2005, 51). More specifically, KM measurement is discussed throughout the manual (OECD/Eurostat 2005, 24, 77, 87 and 125), drawing on the work in OECD (2003). Within the series of Community Innovation Surveys, the four questions about the adoption of KM practices, used in Kremp and Mairesse (2003) to estimate KM intensity, have been used again in CIS4.

A final reason to be optimistic about the development of a rich indicator base for the knowledge economy is that, even in the absence of a large international survey using standardized procedures for data collection on KM, empirical studies on the economic impact of KM (as well as of other new human resource practices) are proliferating (see Hall and Mairesse 2006), all of them concluding that such new practices enhance performance (see Shaw 2004, for a survey). Of course, all these studies are based on partial surveys, ad hoc datasets and datasets that are not purpose-designed.

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Hence, the studies are extremely costly and have a poor potential for international comparisons and benchmarking. However, although each of these studies seems vulnerable and open to criticism on many counts when considered alone, the overall convergence of their results is quite convincing.

The success of the CIS, as well as the increasingly large body of empirical research on KM and organizational innovation, based on firm-level data, show that the future of the economics of knowledge as a strong empirical discipline is promising, and that the objective of enriching its indicator base is achievable.

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Chapter 7

TOWARDS UNDERSTANDING THE IMPACTS OF SCIENCE, TECHNOLOGY AND INNOVATION ACTIVITIES

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Charlene Lonmo, Chuck McNiven, Susan Schaan,
Mark Uhrbach, Bryan van Tol and Ben Veenhof
Statistics Canada

7.1. Context

For centuries, science, technology and innovation (STI) activities have been one of the driving forces of economic and social change. The transformation of the developed economy from one based on natural resources to a globally integrated system based on knowledge and information could not have occurred without the adoption of scientific principles or the implementation of innovative technology. Similarly, STI activities have accelerated growth and brought about social change through the movement of people, goods and services, and through an increased capacity to generate, transmit and use STI knowledge.

Despite the importance of STI activities, much of the existing information about them relates only to inputs: for example, who is involved in which activity and what is the nature of that activity? These basic measures are essential for tracking who is doing what, where, how and why. However, they are less useful for assessing the outcomes and impacts of STI activities. Although some current indicators do provide information on the immediate outputs of STI activities, the focus is now shifting to more sophisticated measures of the potential value added and costs of STI, and their longer-term implications for the economy and society.

This chapter presents Canadian initiatives geared towards understanding the social and economic impacts of STI activities. In particular, it discusses measures currently used by Statistics Canada and other agencies to describe STI activities and offers new approaches to understanding their impacts. A discussion of the need for and challenges of impact indicators is also included, as well as recommendations for the future direction of this work.

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7.2. The need for indicators

Indicators serve many purposes. They can be linked to policy issues through analysis in order to guide decision-making; they can be used to monitor and evaluate programs; and they are needed for benchmarking and comparison purposes, both over time and across countries. Whatever the intended purpose, indicators provide relevant information about the state of the economy or society through the use of statistics.

Whereas activity indicators are needed for descriptive analyses and decisions about funding, and indicators of linkages are important for illustrating how various parts of the economy and society are interconnected, outcome and impact indicators are crucial for evidence-based policy, resource allocation and accountability requirements (Gault 2006).

7.2.1. Developing indicators

For relevant indicators to be developed there must be a demand for them. They must feed into the policy process, evolving over time and according to changes in policy priorities. For Statistics Canada, this means maintaining a relationship with the main users of the statistical and analytical outputs, including policy departments, key stakeholders and international bodies, such as the Organisation for Economic Co-operation and Development (OECD).

Canada has been engaged for some time in the development of indicators and the collection of data for a number of STI activities, including research and development (R&D), innovation, intellectual property (IP) and its commercialization, and technology adoption and diffusion. Work began with programs intended to obtain insights into inputs and outputs of STI activities, which then led to a broader focus on STI linkages and outcomes (for example, the uses of information and communication technologies (ICTs), determinants of innovation, new technology adoption and business practices). There is now a push to move even further towards understanding the impacts associated with STI.

All along, Canada has contributed to, and benefited from, the development of internationally agreed guidelines, definitions and classifications for the measurement of STI through active participation at the OECD's Working Party of National Experts on Science and Technology Indicators (NESTI) and the Working Party on Indicators for the Information Society (WPIIS). International collaboration and coordination are essential if work on STI outcomes and impacts is to continue to advance.

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7.3. The challenges of assessing impacts

Impacts are not easily defined or measured. Work in this area is still in the early stages, and there are no established frameworks on which to build. One of the more obvious difficulties is the fact that impacts can take some time to emerge into observable phenomena. In some cases, the outcomes and impacts of STI activities have not yet been fully absorbed into the economy or society. For example, it is clear that Internet use has brought about changes in social behaviours, but the broader impacts of these changes are still unfolding.

In addition, impacts are often difficult to identify and cannot easily be traced back to their origins. Impacts are also multi-dimensional: they can be both positive and negative; they can be direct or indirect; they can vary among actors (*e.g.* individuals, firms); they can affect the economy, society and more; and they can affect the environment surrounding STI activities that results from changes in STI policy or strategy (Statistics Canada 1998a).

Finally, impacts cannot be measured in the same way as activities. They are better understood through a combination of surveys and analytical techniques, rather than through direct assessment from survey instruments alone. This approach is useful for identifying the linkages and outcomes of STI activities, which can then be used analytically to shed light on impacts. Some examples of analytical techniques used for this purpose include econometric modeling (Klassen and Carnaghan 2006; Sciadas, Clermont and Veenhof 2005; Veenhof 2006) and microeconomic simulation modeling (Wolfson 1995). A case study or data linkage approach (Baldwin and Sabourin 2001, 2004) would also add value to the study of impacts.

7.4. A systematic view of STI indicators

The first and most basic step towards understanding impacts in the context of STI indicators is establishing a framework. A framework not only helps to guide statistical work and identify measurement gaps, but also provides a better understanding of how different indicators are connected.

7.4.1. A framework for STI indicators

Shortly after the first Blue Sky conference, Statistics Canada – in consultation with Industry Canada, members of the Advisory Committee on Science and Technology Statistics and its Working Group, and others – developed a framework for a statistical information system for science and technology (S&T) (Statistics Canada 1998a). The structure of the system comprises an *actor* or set of *actors* engaged in *activities*, the *linkages* and resulting *outcomes*, leading to economic and social *impacts*.

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Indicators that describe the *actors* and *activities* are of great importance in the early stages of measurement, capturing who is doing what STI activities, where, how and why. As time passes and policy needs evolve, interest shifts to measures of *linkages*. These may include the flow of graduates to industries, the sources of funding, and the licensing of IP from government or universities.

Measures eventually begin to address the *outcomes* and *impacts* of STI. If outputs are the direct result of STI activities (number of patents granted, articles published, new products produced), then outcomes are the medium-term result of STI activities (more skilled employees, greater market share). These can typically be measured through administrative or survey data. Impacts, however, are the longer-term consequence of activities, linkages and outcomes. For the reasons discussed in the preceding section, these are more difficult to measure and are usually, but not always, addressed analytically. Some practical examples of the system follow.

- A small firm (*actor*) conducts R&D in telecommunications (*activity*), which requires a team of skilled employees and venture capital funds (*linkages*). The result is a new cellular telephone (*outcome*), which has an *impact* on the communication patterns of individuals and the organizational practices of business.
- Universities (*actors*) engage in innovation in biotechnology (*activity*) through collaborative partnerships with government (*linkages*). The result is a life-saving heart medication (*outcome*), leading to an improved quality of life for those who take it and changes in labour demand by the pharmaceutical industry (*impacts*).

7.4.2. A conceptual model

Figure 7.1 illustrates the relationships in the STI system. This model recognizes that actors generate, transmit and use STI knowledge by engaging in activities. Linkages represent the means by which STI knowledge is transferred between actors and through activities, leading to measurable outputs and intermediate outcomes. In turn, linkages, outputs and outcomes lead to a wide range of longer-term impacts.

While the model describes the flow of STI knowledge through the system, it also takes into account the complexities of existing indicators and the development of new ones. For example, measures of linkages and outcomes contribute to a better understanding of impacts; output indicators can be partial measures of impacts (Arundel 2006); and impacts can influence the generation, transmission and use of new STI knowledge, as the cycle begins again.

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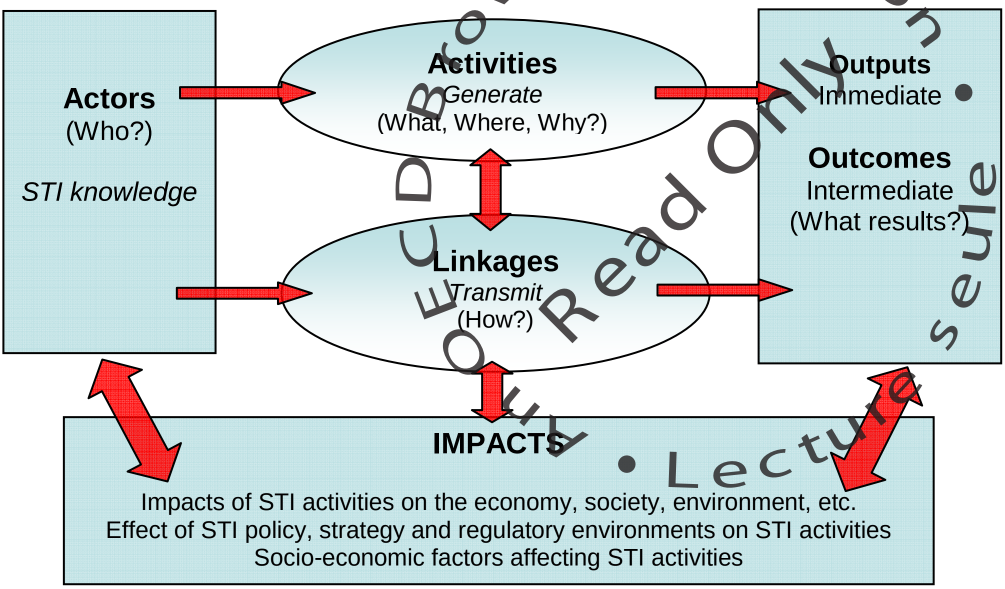
Figure 7.1. A conceptual model for STI indicators



Source: Adapted from Statistics Canada (1998a) and OECD (2005).

7.5. Existing measures

A number of initiatives are currently underway that use existing measures of STI to shed light on impacts. For example, linkages between the use of information and communication technology (ICT) and a number of social and economic outcomes, including literacy, income and time use, have already been made. The impacts of ICT on communication and spending patterns, as well as on people's work and leisure time, are being explored, and work is progressing on linking innovation to commercialization, and R&D investments to results.

7.5.1. Innovation, commercialization and IP

The *Oslo Manual* (OECD/Eurostat 2005) already contains advice on how to interpret the impacts of innovation. To date, national surveys have focused on factors that affect the bringing of the first copy of a product to market, with some indicators of the percentage of sales due to new or significantly improved products. Statistics Canada's Survey of Innovation 2005 (Statistics Canada 2006a) is based on the principles of the *Oslo Manual*, as well as on the approach adopted by the Community Innovation Survey (CIS). It includes detailed questions to elicit a better understanding

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of the nature of innovation and its commercialization at the firm level, including business success factors and obstacles, sources of information and impacts of innovation.

One of the more important research questions in this area relates to the relationship between innovation and firm performance. The characteristics of innovative and non-innovative firms, particularly in the Canadian service sector, have been examined with a view to gaining more information about this association. To obtain a better understanding of the impacts of innovation and technological change, the survey goes beyond the "core" questions, addressing the link between innovation and human resource capability, the flow of innovative goods and services (supply chain) and outsourcing, and the creation and loss of jobs.

In addition, a new "impact" module in the 2005 survey has improved understanding of the linkages and outcomes associated with innovation activity. Firms were asked to indicate the degree of importance of various impacts, such as increased range of goods or services, improved flexibility of production or service provision, increased plant productivity, increased market share, reduced environmental impacts, and improved health and safety.

If innovation is defined as the first commercial use of a new or significantly improved product or process, then commercialization can be seen as one aspect of the economic impacts of STI activities. Most questions in the early innovation surveys related only to the introduction of an innovation. The 2005 revisions to the *Oslo Manual* (OECD/Eurostat 2005) broadened the wording to include organizational structures and management practices, as well as innovation activities or projects and commercialization. These revisions have led to new indicators of innovation, which show how knowledge from different sources combines to add value to a firm, leading to impacts on business and people (Gault 2006).

Survey questions about innovation activities also address the introduction of innovations to the market and post-introduction commercialization. Others ask about barriers to the commercialization of innovation, and questions on sources of funding and support for commercialization are also included.

In a first step towards a better understanding of the economic impacts of STI activities, Statistics Canada is undertaking a set of feasibility studies, using **case studies**.

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- **Pre-commercialization activities in universities, government and the private sector.** What approaches are organizations using to optimize the commercialization potential of their research effort (*i.e.* activities ranging from directing research into "commercializable" areas to business planning and marketing potential technologies)?

- **Private-sector licensing (in and out).** What are the national and international sources of the technologies being used in the private sector? What is the value of publicly funded technology? What is the destination of the technology developed in Canada? What are the regional, sectoral and international destinations? This study will develop an approach to tracing licensing between sectors, countries and regions.

- **Private-sector IP management.** Are inventions being reported, patented and licensed? What is the propensity of Canadian companies to protect their IP and of managers to recognize the commercial potential of their inventions? Indicators similar to those in the public-sector IP management surveys will be developed.

- **The importance of management capacity.** What skills are required to obtain optimal benefits from technology – for example, recognition of market potential (vision); business and management skills (funding, organization, production); technological skills; legal skills (IP management)? Are businesses with access to these skills more likely to innovate, to commercialize, to be successful?

- **The relative contribution to sales of process innovation.** Surveys of innovation ask for the proportion of sales from new or significantly improved products. This study will attempt to determine the extent and nature of the contribution of new processes by reporting on their characteristics and their impact on products produced.

- **Commercialization of R&D and small R&D performers.** This study will develop *a)* an approach to tracing R&D effort to the marketplace; and *b)* an understanding of why many smaller R&D performers conduct R&D intermittently. An interviewer guide has been prepared (Statistics Canada 2006b), and a summary of interview findings released (Rosa and Rose 2007). Surveys will follow.

- **Commercialization of innovation.** What actions are taken to maximize the commercial benefits from innovation? What barriers remain to obtaining optimal benefits? To what extent are inventions being patented and licensed abroad? Questions on marketing activities are included in Statistics Canada's Survey of Innovation 2005; however, additional work will develop an approach to determining the contribution of com-

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mercialization activities to the proportion of sales from new or improved products.

One component of these studies, IP management, is already understood to some degree for the public sector. Statistics Canada has been conducting surveys in the higher-education sector and in federal departments since 1998 to determine how to maximize the benefits resulting from public-sector research. Indicators include IP management infrastructure and expenditures, number of patents held and commercialized, and licensing. One of the main insights gained from these surveys is that the direct returns from licensing income are very small compared to the original outlay of R&D. Total royalties for all universities in 2004 were about $56 million (Read 2006). The presumption is that the benefits to the economy of IP licences are many times that value. Furthermore, the benefits of *unlicensed* IP (*i.e.* published papers, consulting activities, know-how gained) are probably very large as well. One of the objectives of the commercialization studies is to determine the value to the public sector of IP transferred from the public sector to the private sector.

Bordt and Earl (2004) conducted a preliminary investigation into the benefits of public-sector IP to the private sector. About 4 120 firms reported that they licensed technologies from the public sector (institutes of higher education, government and hospitals). Over 4 400 reported that technology acquired from the public sector played a major role in the firm's success. The commercialization studies will develop means of asking these companies what the value is to them of the technology that has been transferred.

7.5.2. R&D

Canada's federal government is a major player in S&T, investing over $9 billion each year through direct support for businesses, universities and federal R&D, and related scientific activities (RSA) (Statistics Canada 2006c). Existing data-gathering efforts follow the guidelines of the *Frascati Manual* (OECD 2002) and focus primarily on S&T inputs – R&D expenditures by performing and funding sector, R&D personnel, socio-economic objectives of R&D, application of R&D, linkages between R&D performers and funders, and the number of full-time equivalents (FTEs) engaged in R&D. There is limited information about the results and outcomes of R&D investments.

Work led by Industry Canada's Innovation Policy Branch, in partnership with Statistics Canada and others, is underway to strengthen the linkages between R&D investments and outcomes for Canadians, as well as the current knowledge base on the impacts of federal S&T investments.

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Specifically, this work will build on information already collected on the socio-economic objectives of the R&D performed, as well as data on patents and royalties from federal laboratories and universities. The results indicators project will help to develop a more detailed picture of these investments, determine areas for improvement in federal support, and identify larger social and economic impacts of government expenditures on business R&D. A number of related projects are underway.

- **Current measures for federal government R&D activity.** Determine the current federal government results indicators for R&D expenditures.
- **Linkage of R&D expenditures to results indicators.** Use a sample of government R&D projects linking expenditures and results, and best practices to build a database for results indicators.
- **Commercialization feasibility studies.** Measure the value of, barriers to and impacts of commercialization activities.

7.5.3. Advanced technologies

The adoption and integration of advanced technologies into business may have important social and economic outcomes and impacts, which can be explored both qualitatively and quantitatively. Existing Statistics Canada programs measure the level of advanced technology diffusion across industries, as well as the actors, activities, linkages and outputs associated with technology diffusion.

7.5.3.1. Manufacturing technology

The impacts of advanced manufacturing technology (AMT) are being explored by linking AMT surveys to production surveys. To reduce the burden of and ensure consistency of response, the approach taken is to link the results of surveys that collect mostly qualitative data to the results of quantitative production surveys. These data linkages have demonstrated that manufacturing establishments using AMTs outperform those that do not (Baldwin, Diverty and Sabourin 1995; Baldwin and Sabourin 2001, 2004; Baldwin, Sabourin and Smith 2003). Moreover, advanced technology adoption in the manufacturing sector has been shown to lead to better jobs, and higher wages and salaries than non-adoption. Other impacts include gains in market share at the expense of non-adopters and growth in labour productivity.

Responses from surveys containing qualitative questions are also useful for understanding the outcomes and impacts of AMT adoption. For example, technology adoption may result in the need for more training and/or a shortage of skills to operate the technology. In turn, the actions taken by

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plants in response to advanced technology adoption will have additional impacts. Such issues were explored in the 1998 Survey of Advanced Technology in Canadian Manufacturing (Arundel and Sonntag 1999), in which information was collected on technology use, skill shortages and actions taken to deal with shortages, such as employee training. This type of information begins to address the cycle of STI indicators by tracking the activities, linkages and resulting outcomes.

Arundel and Sonntag (1999) found that skill shortages increased AMT investment shares (the percentage of total investment in machinery and equipment spent on AMTs in the previous three years) and the probability of adopting a new type of AMT. Although skill shortages increase costs through training, and higher wages and salaries, they do not prevent plants from acquiring new AMTs.

Work is already underway on the 2007 Survey of Advanced Technology for Manufacturing and Logging. The survey will include detailed questions about advanced technology adoption and planned use, as well as results and outcomes. In particular, respondents will be asked to rate the impact of a number of effects following the adoption of advanced technology, including: reduced labour requirements per unit of output (productivity); reduced time to market, improvement in product quality (product improvement); increased flexibility, customization, specialization or skill requirements (business unit organization); reduced energy costs (business unit efficiencies); increased profitability, opening new export markets (market performance); and reduction of environmental impacts. The new survey will also address linkages between innovation and technology adoption.

7.5.3.2. Biotechnology

Canada has pioneered a number of important concepts and data collection initiatives related to biotechnology. Beginning with a pilot survey in 1997, Statistics Canada has conducted the Biotechnology Use and Development Survey (Statistics Canada 2007a) in alternating years. The survey was designed to begin to measure direct outputs and outcomes, including indicators of business practices and revenues, counts of products on the market, employment in biotechnology activities, expenditures on R&D, IP management, use of tax incentives, costs of regulatory compliance and sources of funds. Existing social outcome indicators for biotechnology are related to human resources – employment, unfilled job openings, recruiting from abroad, spinoffs from public organizations, impact on employment of contracting activities, and collaborative arrangements. Some of these concepts can also be extended to the previously mentioned work on commercialization (*i.e.* the granting and obtaining of IP rights).

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Statistics Canada conducted the world's first Bioproducts Development Survey in 2004 (Statistics Canada 2005a), which aimed to capture the development and production of these alternative products in Canada. This information, albeit limited, offers the potential to begin an assessment of the impacts of bioproducts development; existing economic measures include rates of use by firms and values of sales from bioproducts (relative to traditional products). Similarly, the Functional Foods and Nutraceuticals Survey (Statistics Canada 2003) provides financial measures of firms engaged in the production or development of these products, including revenues, exports and R&D, both as a total for the firm and as they relate to functional foods and nutraceuticals. The survey also addresses business practices, raising capital, IP and human resources. Some analysis has been done to examine the impacts of regulation on functional food and nutraceutical product activities (Tebbens 2005). This study reported that about 40% of firms would be willing to conduct research to support health claims related to functional foods and nutraceuticals if labeling regulations were changed. Firms were also asked about the perceived impact of changes to regulations on domestic sales, export sales, and ability to compete with global competitors.

7.5.3.3. ICT

Much attention has been directed to ICT indicators, in large part as a result of the World Summit on the Information Society (WSIS), the first phase of which was held in Geneva in 2003 and the second in Tunis in 2005. A number of global initiatives have been completed, including the identification of core indicators for the information society, the completion of the OECD *Guide to Measuring the Information Society* (2005), and the building of capacity to improve ICT indicators globally and in developing countries. Again, most of the existing indicators capture infrastructure, access and use, as well as some linkages and early outcomes.

Understanding ICT impacts is important, not only for guiding policy, but also for making the case for ICT diffusion in developing countries. The link between ICTs and development has been the driving force behind much of the international activity, including the WSIS. Interest in issues such as economic marginalization and social exclusion has led to closer investigations of the "digital divide" (Sciadas 2002; Orbicom 2003, 2005). This work represents a huge step forward in the development of a framework for measuring the divide, monitoring its evolution across a great number of countries, and examining the strengths and weaknesses of country-specific ICT policies.

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Although relatively little has been done to assess the impacts of ICT use by households and individuals, it is accepted that changes are occurring in the way people work, communicate and spend their time. These changes will lead to impacts on the economy and society, but such impacts are not easily measured through official statistics and surveys. Rather, analytical tools are needed to identify the linkages and contribute to the understanding of these impacts.

- **Surveys of Internet use**, beginning with the 1997 Household Internet Use Survey (HIUS) (Statistics Canada 1998b), provided the first indicators of Internet penetration among households. Over time, and as use of the Internet has become more widespread, analytical work has shifted to exploring the linkages and outcomes of ICT. This shift prompted a redesign of the HIUS, leading to the release of the first Canadian Internet Use Survey (CIUS) in 2005 (Statistics Canada 2006d). Now based on individuals, the CIUS allows for a broader analytical approach and, for the first time, uses an internationally comparable dataset to help situate Internet use in Canada in relation to Internet activity in other countries. The availability of data on how the Internet is used and experienced directly by individuals places analysts in a better position to begin to address outcomes.

- **Early outcomes of Internet use** were assessed in the 2000 General Social Survey Cycle 14: Access to and Use of Information and Communication Technology (Statistics Canada 2001). The survey used a direct approach to ask respondents whether their use of the Internet had changed the amount of time they devoted to other activities, such as watching television and spending time with family (Dryburgh 2001).

- **Relationships between literacy skills and ICT use** were explored in a study based on data from the International Adult Literacy and Life Skills Survey (IALS) (Statistics Canada 2005b). The study found that, as literacy skill levels rose, so did other factors, such as the perceived usefulness of computers, diversity and intensity of Internet use, and use of computers for task-oriented purposes. This occurred even when other factors with an impact on computer use, such as age, income and education level, were taken into account. **Outcomes of ICT use** were also investigated: for example, it was found that people who used computers and had higher literacy rates were far more likely to have higher incomes (Sciadas, Clermont and Veenhof 2005).

- A more recent study of **how Internet users spend their time** focused on different economic, social and recreational behaviours among Internet users and non-users (Veenhof 2006). **Changes in communication and spending patterns induced by ICTs** have also been examined (Sciadas

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2006). This type of work enhances understanding of the social outcomes associated with ICT use.

Internationally, much has been done with respect to exploring the economic impacts of ICTs, using macro-data, industry data and micro-data. For example, evidence from firm-level studies suggests that the use of ICT has positive impacts on firm performance and productivity (OECD 2004; Pilat 2005). However, it is important to note that these impacts occur in conjunction with other changes and investments in a firm – for example, improved skills and organizational changes. At the aggregate level, studies have shown that investment in ICT contributes to capital deepening and growth (OECD 2005). An "impacts workshop" at the 2006 WPIIS meetings further highlighted country experiences and analyses in this area (Clayton 2006; Pilat 2006). Following are summaries of some Canadian initiatives.

- A study of the **changing patterns of capital formation and sources of economic growth for Canadian business** began to address the impacts of technological progress and the accumulation of ICT assets on the Canadian business sector. The data show that increases in capital and labour continue to be important contributors to output growth. Multi-factor productivity is also an important source of growth in output (Harchaoui *et al.* 2001).

- **The Survey of Electronic Commerce and Technology (SECT)** (Statistics Canada 2007b) has provided baseline data for ICT adoption by Canadian businesses since 2000. SECT was a "world-first" for a statistical agency in terms of cross-economy measures of e-commerce. Survey questions also address the perceived benefits of and barriers to buying and selling on-line, in an effort to understand linkages and associated outcomes and impacts, although these measures are less objective than empirical measurement techniques.

- **The newly developed researcher database facilitates the use of SECT micro-data for research and analysis** under Statistics Canada's Facilitated Access Program. Recent work involved researchers from the University of Waterloo, who used the database to focus on factors influencing the transition of Canadian firms from one stage of e-business to another. Using the Technology, Organizations and Environment (TOE) framework, the researchers were able to follow individual firms over a three-year period. Preliminary results from the study suggested that firms both progress and regress through the stages of e-business. While a smaller proportion of large firms regressed, very few firms of any size made the jump from having no Web site at all to conducting e-commerce sales on a Web site during the period of study (Klassen and Carnaghan 2006).

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7.6. New approaches

Although work on understanding impacts has been advancing, there is still much to be done. Studies aimed at gaining a better understanding of STI impacts must take into account the fact that, although many impact indicators are comparable across applications (improved health and well-being, increased market share and lower production costs, changing social behaviours), others are application-specific – for example, the annual reduction in greenhouse gases from biofuels (Arundel 2006). Impacts should be assessed with a sense of their relevance to the STI activity concerned. Depending on that activity, they may take longer to observe, which makes them even more difficult to identify. In such cases, one could begin to identify the *potential* outcomes and impacts of the activities, in an attempt to trace them back through measures of linkages. These limitations mean that different approaches to understanding impacts may be required for different STI activities.

- Statistics Canada's **2007 Survey of Commercialization** will provide further insight into the benefits of public-sector technology transferred to the private sector, the proportion of R&D that is commercialized, and the contribution of revenues from process innovation. Research in the area of IP management in the public sector and results from a new survey on business incubators will give rise to alternative approaches to and measures of impacts.

- There are two types of **outcomes for products and processes developed through biotechnology activities**: those that are substitutions for or improvements of existing products or processes; and those that are entirely novel or radical. The impacts from these outcomes could be assessed in different ways. Assessment of the impacts of substitution, for example, could address the reasons for it – less expensive, more reliable/less risk.

- **The public sector is a major source of new knowledge, which leads to market activities through the commercialization of IP and the creation of spinoffs**. The public sector is also a tester and early adopter of new technology, helping to influence the diffusion and adoption of technology and practices as they become more generally accepted. To advance the work of STI outcomes and impacts, it is important to continue and improve measurement activities for the public sector.

- Work has also begun on **understanding the role of organizational practices, such as knowledge management, in firms' productivity and survival**. This type of organizational innovation further highlights the linkages between knowledge generation, transfer and use within the

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firm and the economy. Developing a better approach to understanding organizational innovation – especially its impacts – should be a priority.

- Studies of the impacts of ICT use have typically relied on direct assessment through respondent perceptions. As ICT penetration rates have begun to reach saturation levels in some countries, there is a need for **new insights into ICT linkages and outcomes**, whether through time-use studies, longitudinal studies or other instruments, such as micro-simulation. One approach is to examine the expected outcomes associated with ICT retrospectively to assess whether they have occurred. For example, Sciadas (2006) used statistical information to demonstrate that the "paperless" society, the reduction in physical mail and the end of traditional retail have – so far – not materialized. Related questions were also addressed in the study: How and to what extent has the availability of on-line shopping changed the shopping behaviour of Canadians? How has the adoption of digital technologies affected individual communication patterns?

- Statistics Canada's Facilitated Access Program provides researchers with **access to micro-data**, subject to project approval and user fees. This program contributes to the basic framework of STI activities – the generation, transmission and use of STI knowledge. Participating surveys include the 1998 Survey of Advanced Technology in Canadian Manufacturing, the Survey of Innovation, the Biotechnology Use and Development Survey and SECT. The use of micro-data as a tool to assess impacts should be encouraged. Linking activity surveys with financial or administrative sources would also enhance understanding of impacts.

7.7. Main recommendations

The proposed recommendations offer the international community opportunities for extending work on impacts beyond what has been possible for individual countries. The development of new indicators and new approaches for understanding impacts should be a collaborative effort, beginning with an agreed framework for indicators. This will ensure internationally comparable measures and a recognized set of guidelines, which can be used to steer STI policy for the next decade.

It is therefore recommended that experts, policy makers, national statistical offices and international organizations:

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- Coordinate their activities to develop an agreed conceptual framework for STI impact indicators;
- Coordinate the development of guidelines, indicators and approaches for assessing STI impacts, recognizing the benefits of international comparability, but ensuring that indicators meet national priorities for policy making and planning; examples of indicators that could be developed include:

Innovation, commercialization and IP

- The success rate of commercialization (measured as a ratio of expenditure on R&D resulting in commercialization – licences, patents, inventions and spinoff companies – to total expenditure on R&D).
- The proportion of patents (government, higher-education and private-sector) that has been assigned or otherwise commercialized.
- The proportion of sales due to new or significantly improved processes, marketing innovations and organizational change.
- The value and utility of products and processes perceived by consumers.
- Measures of work culture and structures.
- A conceptual framework linking innovation, commercialization and productivity (as recommended in the *Oslo Manual* (OECD/Eurostat. 2005, para. 413); see Bordt *et al.* 2005).
- Definitions of international core concepts and model questionnaires for IP management in public and private sectors.

Biotechnology, bioproducts, and functional foods and neutraceuticals

- The perceived impacts of products/technologies, *i.e.* screening technology for early diagnosis.
- The purpose of products/technologies (health, environment, agriculture), *i.e.* to reduce the use of pesticides.

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ICT

- Measures of social outcomes/behaviours – health and well-being, employment, spending patterns, time use, communication patterns, social networks.
- Measures of ICT divides – rural-urban, gender, age, education, income – to determine how more intense use of ICT and/or type of Internet use affect the gap between ICT "haves" and "have-nots".
- Measures of economic outcomes – the impact of broadband, e-commerce efficiency, organization of work, firm performance.
- Measures of ICT skills (or digital literacy) – the ability to navigate, retrieve, and interpret and apply information using a variety of methods and formats.
- Continuation of capacity building and information exchange through international working groups, such as the WPIIS Expert Group on ICT Impacts.
- Further develop analytical techniques and tools to trace pathways and identify sequences of events.
- Build on linkages and associations to gain a better understanding of decision-making, changes in behaviours, outcomes and impacts by:
    - Making use of different types of data (micro-data, longitudinal data);
    - Making use of different analytical approaches (case studies, data linkage);
    - Making use of different analytical techniques (econometric modeling, microeconomic simulation modeling); and
    - Focusing on attempts to understand individual businesses by linking financial data with firm activities to follow firms over time (*i.e.* survival and growth studies).

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Part Four

THE CHANGING KNOWLEDGE LANDSCAPE AND THE NEED FOR NEW METRICS

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Chapter 8

DEMOCRATIZING INNOVATION: THE EVOLVING PHENOMENON OF USER INNOVATION[1]

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8.1. Introduction

When researchers say that innovation is being democratized, they mean that users of products and services – both firms and individual consumers – are increasingly able to innovate for themselves. User-centred innovation processes offer great advantages over the manufacturer-centred innovation development systems that have been the mainstay of commerce for hundreds of years. Users that innovate can develop exactly what they want, rather than relying on manufacturers to act as their (often imperfect) agents. Moreover, individual users do not have to develop everything they need on their own: they can benefit from innovations developed and freely shared by others.

User-centred innovation processes are very different from the traditional, manufacturer-centred model, in which products and services are developed in a closed way, with the manufacturers using patents, copyrights and other protections to prevent imitators from getting a free ride on their innovation investments. In the manufacturer-centred model, a user's only role is to have needs, which manufacturers then identify and fill by designing and producing new products. This traditional model does fit some fields and conditions. However, a growing body of empirical work shows that users are the first to develop many, and perhaps most, new industrial and consumer products. Further, there is good reason to believe that the importance of product and service development by users is increasing over time.

1. An overview of von Hippel (2005).

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The trend towards the democratization of innovation applies to information products such as software and also to physical products, and it is being driven by two related technical trends: *a)* the steadily improving design capabilities (innovation tool kits) that advances in computer hardware and software make possible for users; and *b)* the steadily improving ability of individual users to combine and coordinate their innovation-related efforts through communication media such as the Internet.

The ongoing shift of innovation to users has some very attractive qualities. It is becoming progressively easier for many users to get precisely what they want by designing it for themselves. Innovation by users also provides a very necessary complement to and feedstock for innovation by manufacturers. Moreover, innovation by users appears to increase social welfare. At the same time, the shift of product development activities from manufacturers to users is painful and difficult for many manufacturers. Open, distributed innovation is "attacking" a major structure of the social division of labour. Many firms and industries must make fundamental changes to long-held business models in order to adapt. Further, while government policy and legislation sometimes preferentially support innovation by manufacturers, considerations of social welfare suggest that this must change. The workings of the intellectual property (IP) system are of special concern. But, despite the difficulties, a democratized and user-centred system of innovation appears well worth the effort.

Today, a number of researchers are working to enhance understanding of user-centred innovation processes. This chapter offers a review of some collective learning on this important topic to date.

8.2. The importance of innovation by users

Users, as defined here, are firms or individuals that expect to benefit from using a product or service. In contrast, manufacturers expect to benefit from selling a product or service. A firm or an individual can have different relationships to different products or innovations. For example, Boeing is a manufacturer of airplanes, but it is also a user of machine tools. If one were examining innovations developed by Boeing for the airplanes it sells, Boeing would be considered a manufacturer-innovator in those cases. But, if one were examining innovations in metal-forming machinery developed by Boeing for in-house use in building airplanes, they would be categorized as user-developed innovations and in those cases Boeing would be considered a user-innovator.

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Innovation user and innovation manufacturer are the two general "functional" relationships between innovator and innovation. Users are unique in that they alone benefit *directly* from innovations. All others (here lumped together under the term "manufacturers") must sell innovation-related products or services to users, indirectly or directly, in order to profit from innovations. Thus, to profit, inventors must sell or license knowledge related to innovations, and manufacturers must sell products or services incorporating innovations. Similarly, suppliers of innovation-related materials or services must sell them – unless they have direct use for the innovations – in order to profit from them.

The "user" and "manufacturer" categorization of the relationships between innovator and innovation can be extended to specific functions, attributes or features of products and services. When this is done, different parties may turn out to be associated with different attributes of a particular product or service. For example, householders are the users of the switching attribute of a household electric light switch: they use it to turn lights on and off. However, switches have other attributes, such as "easy wiring" qualities, that may be used only by the electricians who install them. Therefore, if an electrician were to develop an improvement to the installation attributes of a switch, it would be considered a user-developed innovation.

Both qualitative observations and quantitative research in a number of fields clearly document the important role that users play as first developers of products and services later sold by manufacturing firms. Adam Smith (1776) was an early observer of the phenomenon, pointing out the importance of "the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many" (14). Smith went on to note that "a great part of the machines made use of in those manufactures in which labour is most subdivided, were originally the inventions of common workmen, who, being each of them employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it" (17). Rosenberg (1976) explored the matter in terms of innovation by user firms rather than by individual workers. He studied the history of the US machine tool industry, finding that important and basic machine types like lathes and milling machines were first developed and built by user firms with a strong need for them. Textile manufacturing firms, gun manufacturers and sewing machine manufacturers were important early user-developers of machine tools.

Quantitative studies of user innovation document the fact that many of the most important and novel products and processes in a range of fields have been developed by user firms and by individual users. Thus, Enos (1962) reported that user firms developed nearly all the most important innovations in oil refining. Similarly, Freeman (1968) found that user firms

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developed the most widely licensed chemical production processes. Von Hippel (1988) discovered that users were the developers of about 80% of the most significant scientific instrument innovations, and also the developers of most of the major innovations in semiconductor processing. Pavitt (1984) determined that a considerable amount of invention by British firms was for in-house use. Shah (2000) found that the most commercially important equipment innovations in four sporting fields tended to be developed by individual users.

Empirical studies also show that many users – from 10% to almost 40% – engage in the development or modification of products (Table 8.1). About half of these studies do not determine representative frequency of innovation, as they are designed for other purposes. Nonetheless, when taken together, the findings make very clear that users are doing a great deal of product development and modification in many fields.

Table 8.1. Studies of user innovation frequency

Innovation area	Number and type of users sampled	% of users developing and building product for own use
Industrial products		
1. Printed circuit computer-aided design (CAD) software[a]	136 user firm attendees at a PC-CAD CONFERENCE	24.3
2. Pipe hanger hardware[b]	Employees in 74 pipe hanger installation firms	36
3. Library information systems[c]	Employees in 102 Australian libraries using computerized online public access catalogue (OPAC) library information systems	26
4. Surgical equipment[d]	261 surgeons working in university clinics in Germany	22
5. Apache OS server software security features[E]	131 Technically sophisticated Apache users (Webmasters)	19.1
Consumer products		
6. Outdoor consumer products[f]	153 Recipients of mail-order catalogues for outdoor activity products for consumers	9.8
7. "Extreme" sporting equipment[g]	197 Members of four specialized sporting clubs in four "extreme" sports	37.8
8. Mountain biking equipment[h]	291 Mountain bikers in a geographical region known to be an "innovation hot spot"	19.2

Sources: [a]Urban and von Hippel (1988); [b]Herstatt and von Hippel (1992); [c]Morrison, Roberts and von Hippel (2000); [d]Lüthje (2003); [e]Franke and von Hippel (2003b); [f]Lüthje (2004); [g]Franke and Shah (2003); [h]Lüthje, Herstatt and von Hippel (2002).

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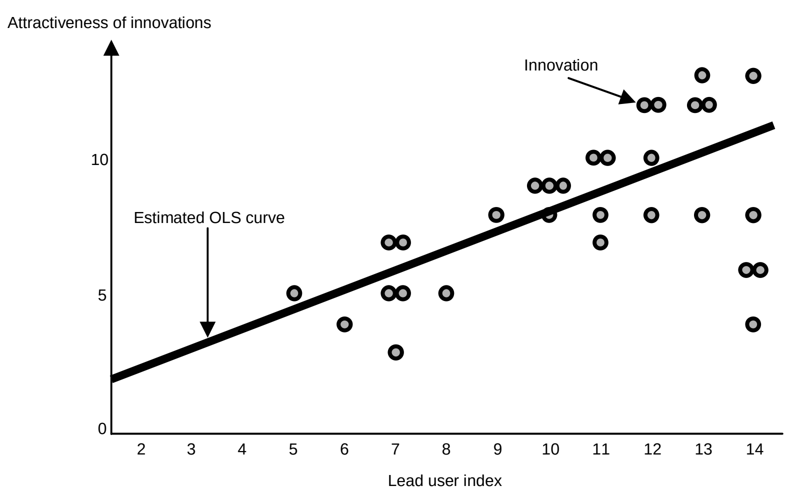
Studies of innovating users (both firms and individuals) show them to have the characteristics of "lead users" (Urban and von Hippel 1988; Herstatt and von Hippel 1992; Olson and Bakke 2001; Lilien *et al.* 2002). That is, they are ahead of the majority of users in their population with respect to an important market trend, and they expect to gain relatively significant benefits from their solution to the needs they have encountered. The correlations found between innovation by users and lead user status are highly significant, and the effects are considerable (Franke and Shah 2003; Lüthje, Herstatt and von Hippel 2002; Morrison, Roberts and von Hippel 2000).

Since lead users are at the leading edge with respect to important market trends, one would guess that many of the novel products they develop for their own use would appeal to other users too and so might provide the basis for products that manufacturers would wish to commercialize. This is, in fact, the case. A number of studies have shown that many of the innovations reported by lead users are judged to be commercially attractive and/or to have been commercialized by manufacturers.

Figure 8.1. Correlation between lead user characteristics and attractiveness of innovations



Estimated OLS function: Y = 2.06 + 0.57x
where
Y = attractiveness of innovation
x = respondents' strength of lead user characteristics
Adj. $R^2 = 0.281$; $p = 0.002$; $n = 30$

Source: Franke and von Hippel (2003a).

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Research provides a firm basis for these empirical findings. Significant correlations have been found between the two defining characteristics of lead users and the likelihood that those users will develop new or modified products (Morrison, Roberts and Midgley 2004). In addition, it has been found that the higher the intensity of lead user characteristics displayed by an innovator, the greater the commercial attractiveness of the innovation that the innovator develops (Franke and von Hippel 2003a). In Figure 8.1, the increased concentration of innovations towards the right indicates that the likelihood of innovating is greater for users with higher lead user index values. The rise in average innovation attractiveness from left to right indicates that innovations developed by lead users tend to be more commercially attractive. (Innovation attractiveness is the sum of the novelty of the innovation and the expected breadth of market demand.)

8.3. Why do many users want custom products?

Why do so many users develop or modify products for their own use? Users may innovate if, and as, they want something that is unavailable on the market and they are able and willing to pay for its development. It is likely that many users do not find what they want on the market. Meta-analysis of market-segmentation studies suggests that users have highly heterogeneous needs for products in many fields (Franke and Reisinger 2003).

Mass manufacturers tend to follow a strategy of developing products designed to meet the needs of a large market segment well enough to induce purchase and capture significant profits from a large number of customers. When users' needs are heterogeneous, this strategy will leave many users somewhat dissatisfied, and some seriously dissatisfied, with the commercial products on offer. In a study of a sample of users of the security features of Apache Web server software, Franke and von Hippel (2003b) found that users had highly heterogeneous needs, and that many were willing to pay to get precisely what they wanted. Nineteen percent of the users sampled actually innovated to tailor the Apache software more closely to their needs. Those who did so were found to be significantly more satisfied.

8.4. Users' low-cost innovation niches

An exploration of the basic processes of product and service development shows that users and manufacturers tend to develop different *types* of innovations. This is due in part to information asymmetry: users and manufacturers tend to know different things. Product developers need two types of information in order to succeed: need and context-of-use information (generated by users); and generic solution information (often initially

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generated by manufacturers specializing in a particular type of solution). Bringing these two types of information together is not easy. Both are often very "sticky" – that is, costly to move from the site where the information was generated to other sites (von Hippel 1994; Ogawa 1998). As a result, users generally have a more accurate and detailed model of their needs than manufacturers have, while manufacturers have a better model of the solution approach in which they specialize than the user has.

When information is sticky, innovators have a tendency to rely largely on information they already have in stock. Users tend to develop innovations that are functionally novel, requiring a great deal of user-need and use-context information for their development, while manufacturers tend to develop innovations that are improvements on well-known needs and that require a rich understanding of solution information for their development. This "sticky information" effect is apparent in studies of innovation (Riggs and von Hippel 1994; Ogawa 1998).

If the information asymmetry argument is extended one step further, one can see that information stickiness implies that information on hand will also differ among *individual* users and manufacturers. The information assets of a particular user (or a particular manufacturer) will be closest to what is required to develop a particular innovation, and so the cost of developing that innovation will be relatively low for that user or manufacturer. The net result is that user innovation activities will be distributed across many users according to their information assets. With respect to innovation, one user is by no means a perfect substitute for another.

8.5. Why do users often freely reveal their innovations?

The social efficiency of a system in which individual users develop individual innovations is increased if users somehow diffuse what they have developed to others. Manufacturer-innovators partially achieve this when they sell a product or service on the open market (partially, because they diffuse the product incorporating the innovation, but often not all the information that others would need to understand it fully and replicate it). If user-innovators do not somehow also diffuse their innovations, multiple users with similar needs have to develop similar innovations independently – a poor use of resources from the viewpoint of social welfare. Empirical research shows that users often do achieve widespread diffusion by an unexpected means: they "freely reveal" what they have developed. Freely revealing information about a product or service it has developed means that the innovator voluntarily gives up all intellectual property rights (IPRs) to

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that information, and allows all interested parties access to it: the information becomes a public good (Harhoff, Henkel and von Hippel 2003).

The empirical finding that users often freely reveal their innovations has come as a surprise to innovation researchers. On the face of it, one would think that, if a user-innovator's proprietary information has value to others, the user-innovator would strive to prevent free diffusion rather than help others to gain free access to what it has developed at private cost. Nonetheless, it is now clear that individual users and user firms – and sometimes manufacturers – often freely reveal detailed information about their innovations.

The practices involved in open-source software development were important in bringing this phenomenon to general awareness. In these projects, it was clear policy that contributors would routinely and systematically freely reveal codes that they had developed at private expense (Raymond 1999). However, the free revealing of product innovations has a history that predates the advent of open-source software. Allen (1983), in his study of the eighteenth-century iron industry, was probably the first to consider the phenomenon systematically. Later, Nuvolari (2004) discussed it in the early history of mine pumping engines. Free revealing by contemporary users has been documented by von Hippel and Finkelstein (1979) for medical equipment, by Lim (2000) for semiconductor process equipment, by Morrison, Roberts and von Hippel (2000) for library information systems, and by Franke and Shah (2003) for sporting equipment. Henkel (2003) has documented free revealing by manufacturers in the case of embedded Linux software.

Innovators often freely reveal their innovations because it is the best or only practical option available to them. Keeping an innovation as a trade secret is unlikely to be successful for long – too many others have similar knowledge – and some holders of the "secret" information stand to lose little or nothing by freely revealing what they know. Studies have found that innovators in many fields view patents as having only limited value (Harhoff, Henkel and von Hippel 2003). Copyright protection and copyright licensing are applicable only to "writings", such as books, images and computer software.

Innovators' active efforts at free revealing are explicable because it can provide significant private benefits, as well as losses or risk of losses. Users who freely reveal what they have done often find that others then improve, or suggest improvements to, the innovation, to their mutual benefit (Raymond 1999). In addition, users who freely reveal information may benefit from enhancement of their reputation, both from positive network effects due to increased diffusion of their innovation and from other factors.

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Being the first to reveal a particular innovation freely can also enhance the benefits received, and so there can actually be a rush to reveal, much as scientists rush to publish in order to gain the benefits associated with being the first to make a particular discovery.

8.6. Adapting policy to user innovation

Is user innovation a good thing? Welfare economists answer such a question by studying how a phenomenon or change affects social welfare. Henkel and von Hippel (2005) explored the social welfare implications of user innovation. They found that, compared with a society in which only manufacturers innovate, social welfare is probably enhanced by the presence of innovations freely revealed by users. This finding implies that policy making should support user innovation, or at least should ensure that legislation and regulations do not favour manufacturers at the expense of user-innovators.

The changes required of policy making to achieve neutrality with regard to user innovation versus manufacturer innovation are significant. Consider the impact of past and current policy decisions on open and distributed innovation. Research done in the past 30 years has convinced many academics that IP law is sometimes, or often, failing to have its intended effect. IP law was intended to increase the amount of investment in innovation. Instead, it now appears that there are economies of scope in both patenting and copyright that allow firms to use these forms of IP law in ways that are directly opposed to the intent of policy makers and to the public good (Foray 2004). Major firms can invest to develop large portfolios of patents. They can then use these to create “patent thickets” – dense networks of patent claims that give them plausible grounds for threatening to sue across a wide range of IP. They may do this to prevent others from introducing a superior innovation and/or to demand licences from weaker competitors on favourable terms (Shapiro 2001; Bessen 2003). Movie, publishing and software firms can use large collections of copyrighted work for a similar purpose (Benkler 2002). In view of the distributive nature of user innovation, with each one tending to create a relatively small amount of IP, users are likely to be disadvantaged by such strategies.

It is also important to note that users (and manufacturers) tend to build prototypes of their innovations economically by modifying products already available on the market to serve a new purpose. Laws such as the (US) *Digital Millennium Copyright Act* (1998), intended to prevent consumers from illegally copying protected works, can have the unintended side effect of preventing users from modifying products that they have purchased (Varian 2002). Considerations of both fairness and social welfare suggest

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that innovation-related policies should be made neutral with respect to the sources of innovation.

It may be that current impediments to user innovation will be removed by legislation or by policy making. However, beneficiaries of existing law and policy will predictably resist change. Fortunately, a way to evade some of these problems is in the hands of innovators themselves. For example, if many innovators in a particular field decide to reveal freely what they have developed, as they often have reason to do, users can collectively create an information commons (a collection of information freely available to all) containing substitutes for some, or a great deal, of the information now held as private IP. Then, user-innovators can work around the strictures of IP law by simply using these freely revealed substitutes (Lessig 2001). This is essentially what is happening in the field of software: user-innovators in that area now have a choice between proprietary, closed software provided by Microsoft and other firms and open-source software that they can legally download from the Internet and modify as they wish to serve their own specific needs.

Policy making that levels the playing field between users and manufacturers will force more rapid change onto manufacturers, but will by no means destroy them. Experience in fields where open and distributed innovation processes are far advanced shows how manufacturers can and do adapt. Some, for example, learn to supply proprietary platform products that offer user-innovators a framework within which to develop and use their improvements (Jeppesen 2004).

8.7. The diffusion of user-developed innovations

Products, services and processes developed by users become more valuable to society if they are somehow diffused to others that can also benefit from them. If user innovations are not diffused, multiple users with similar needs have to invest to (re)develop similar innovations, which, as was noted earlier, is a poor use of resources from the social welfare standpoint. In the case of information products, users have the possibility of largely, or completely, doing without the services of manufacturers. Open-source software projects are object lessons in how users can create, produce, diffuse, provide user field support for, update and use complex products by and for themselves in the context of user innovation communities. In physical product fields, the situation is different. Users can develop products, but the economies of scale associated with manufacturing and distributing physical products give manufacturers an advantage over "do-it-yourself" users.

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How can, or should, user innovations of general interest be transferred to manufacturers for large-scale diffusion? There are three general methods for accomplishing this: *a)* manufacturers can actively seek innovations developed by lead users to form the basis for a profitable commercial product; *b)* manufacturers can draw innovating users into joint design interactions by providing them with user innovation tool kits; and *c)* users can become manufacturers in order to diffuse their innovations widely (von Hippel 2005).

8.8. Democratizing innovation

Users' ability to innovate is improving radically and rapidly as a result of the steadily improving quality of computer software and hardware, better access to easy-to-use tools and components for innovation, and access to an ever-richer information commons relevant to innovation. Today, user firms and even individual hobbyists have access to sophisticated programming tools for software and sophisticated CAD design tools for hardware and electronics. These information-based tools can be run on a personal computer, and their price is rapidly coming down. As a consequence, innovation by users will continue to increase even if the degree of heterogeneity of need and willingness to invest in obtaining the right product remains constant.

Equivalents of the innovation resources described above have long been available to a few within corporations. Senior designers have been supplied with engineers and designers under their direct control, and with the resources needed to construct and test prototype designs quickly. The same is true in other fields, including automotive and clothing design: think, for instance, of the staffs of engineers and model makers employed to help top automotive designers quickly realize and test their designs.

But if, as has been shown, the information needed to innovate in important ways is widely distributed, the traditional pattern of concentrating innovation-support resources on a few individuals is hugely inefficient. High-cost resources for innovation support cannot efficiently be allocated to "the right people with the right information": it is very difficult to know who these people are before they develop an innovation that turns out to have general value. When the cost of high-quality resources for design and prototyping becomes very low (the trend described here), these resources can be diffused widely, and the allocation problem diminishes in significance. The net result is a pattern of increasing democratization of product and service innovation – a pattern that will involve significant changes for both users and manufacturers.

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Chapter 9

HOW INNOVATIVE ARE NEW ZEALAND FIRMS?

QUANTIFYING AND RELATING ORGANIZATIONAL AND MARKETING INNOVATION TO TRADITIONAL SCIENCE AND TECHNOLOGY INDICATORS

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and
Statistics New Zealand (SNZ)[1]

9.1. Introduction

There is a wide variety of views on the strategies, practices and characteristics of firms that make the greatest contribution to innovation and productivity growth. Internationally, those behaviours that have been found to be positively related to, or a cause of, better firm performance include: research and development (R&D) (*e.g.* Griliches 1998; Guellec and van Pottelsberghe de la Potterie 2001); human resource management (HRM) practices (*e.g.* Ichniowski, Shaw and Prennushi 1997; Lazear 2000; Sels et al. 2006); human capital investment (*e.g.* Black and Lynch 1996; Addison and Belfield 2004); innovation (*e.g.* Crepon, Duguet and Mairesse 1998; Hall and Mairesse 2006); international engagement (*e.g.* Tybout 2000; Criscuolo, Haskel and Slaughter 2005); and information and communication technology (ICT) investments (*e.g.* OECD 2004a; APC 2004).

1. The author is a Chief Advisor (Economic Strategy) at MED on secondment to SNZ, and is an affiliate of Motu Economic and Public Policy Research. The views expressed in this chapter are his and do not necessarily represent any of these organizations. The author wishes to thank Julia Gretton and Hamish Hill (both SNZ) for extremely able research assistance, and Eileen Basher (SNZ), Arthur Grimes (Motu) and Bettina Schaer (MED) for helpful feedback on the chapter.

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What, perhaps, is interesting, given this wealth of evidence, is the rather sparse uptake of many of these "high-performance" activities (Figures 9.5 and 9.6 demonstrate this for New Zealand). Part of the explanation may be that the applicability of such practices will vary according to the characteristics of the markets in which firms operate.[2] The dispersion of practices is also consistent with a resource-based view of the firm, whereby decision-makers within firms make resource allocation decisions using idiosyncratic endowments of knowledge and ability (Penrose 1959; Wernefelt 1984). In this view of the firm, much emphasis is placed on the market search function, or "entrepreneurial spirit," that takes technologies and tests their worth in localized market conditions (*e.g.* Hausmann and Rodrik 2002; Baumol 2002). Interpreted in this light, our understanding of the microeconomics of productivity growth provides empirical evidence consistent with the importance of learning by doing and path dependence (*e.g.* Nelson and Winter 1982; Aghion and Howitt 1998). Two particularly robust results from this literature are the persistence of relative productivity performance over time and the positive contribution of firm turnover to aggregate productivity growth (*e.g.* Haltiwanger, Lane and Speltzer 1999; Bartelsman and Doms 2000; OECD 2004b; Law and McLellan 2005).

From a policy perspective, a narrow view of innovation runs the risk of missing or misattributing the importance of joint strategic decisions, and other activities directed by those decisions, within the firm. Bias can arise in assessing the impact of, for example, R&D or ICT investment if innovation outcomes are attributed entirely to these activities.[3] Good econometric studies, of course, control for firm fixed effects (of which management quality might be a likely contributor), reducing the risk of coefficient bias. However, knowing that the econometric technique has compensated for some missing variables does not shed much light on the debate around government's role in innovation policy and productivity growth – a subject that motivates much of the economic policy agenda in New Zealand (*e.g.* New Zealand Government 2002). As Arundel (2005) points out, policy development can tend to coalesce around what is measured (despite the caveats that researchers place around their work).

2. For example, the usefulness of patents depends, among other things, on the characteristics of the knowledge being protected (Levin *et al*. 1987).

3. Recent case study and empirical evidence regarding business use of ICT (OECD 2004a; APC 2004) emphasizes the importance of strategic intent, complementary investments and organizational change in maximizing the benefit from ICTs. While much knowledge is embodied in the physical capital, firm behaviour needs to be reshaped to capture the gains from such knowledge: for instance, employees may need specific training; supply-chain management may need re-engineering.

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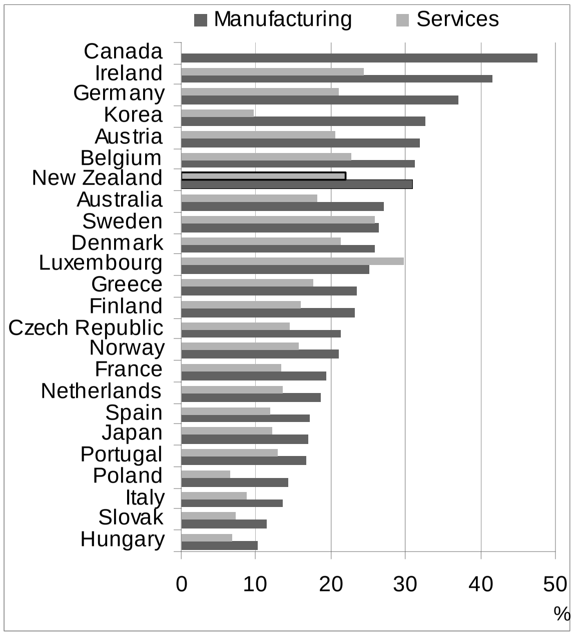
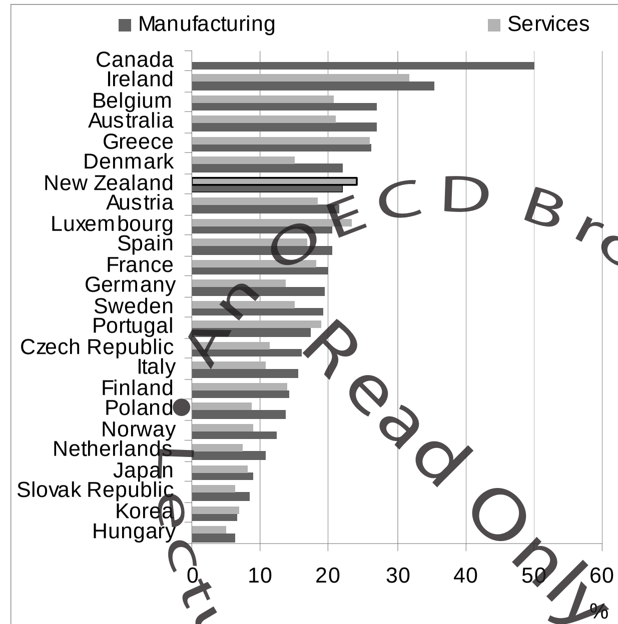
Figure 9.1. New Zealand's innovation performance relative to that of other OECD economies

In-house product innovators by sector (as a percentage of all firms)
2002-04 or latest available year



In-house process innovators by sector (as a percentage of all firms)
2002-04 or latest available year



Source: OECD (2007c), STI Scoreboard, based on Eurostat, CIS-4 (New Cronos, May 2007) and national data sources.

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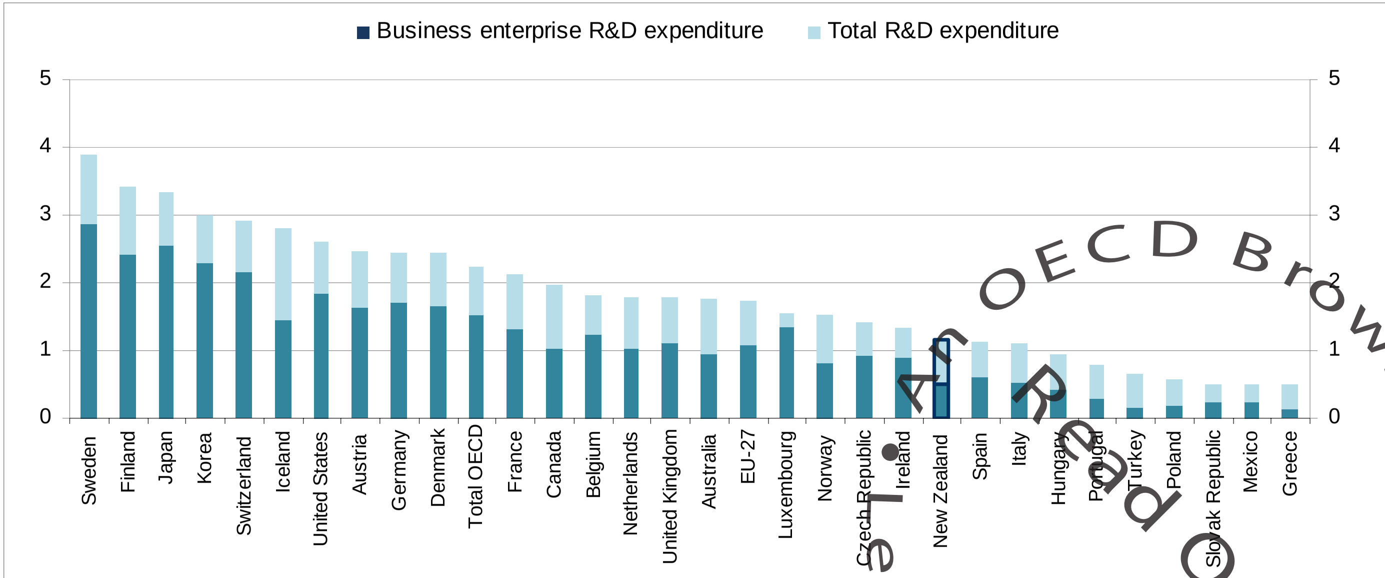
Figure 9.2. R&D expenditure (% of GDP) in 2005 or latest year available[1]



1. 2006 for Finland, United States, Canada and Ireland; 2004 for Switzerland, Netherlands, Australia, Italy and Turkey.

Source: OECD (2007b), Main Science and Technology Indicators.

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Smith (2006), in his assessment of the New Zealand innovation system, emphasizes the importance of taking a systemic view of innovation policy. Even if the policy guidance dictated by the data is correct, risk still arises in policy design if related functions within the firm are not accounted for and appreciated. Would the assessment of best-practice R&D policy be different if the influence of good marketing or customer engagement on firm innovation outcomes were better understood? More generally, from a systems perspective, firms may legitimately choose not to be cutting-edge innovators themselves. How should their non-technological practices be structured to enable them to be "fast adopters" of knowledge generated elsewhere in the (global) economy?

Traditionally, the innovative capability of firms has been assessed by posing such questions as: Do you do (*Frascati Manual*) R&D? Do you own a legal monopoly over intellectual property (*e.g.* a patent)? Do you employ scientists/staff with advanced academic qualifications? Measures of this type generally send a mixed message on the innovative capacity of New Zealand businesses. For example, cross-country comparison of business expenditure on R&D (BERD) suggests relative weakness, while product and process innovation outcomes suggest relatively strong performance (see Figures 9.1 and 9.2).

The key concern of this chapter is to provide some assessment of the potential "mismeasurement" of innovation arising from a pure focus on product and process improvement. To this end, it investigates how broader measurement of innovation changes our understanding of what an innovative New Zealand firm looks like. The chapter attempts to provide a sense of how New Zealand policy agencies are working towards an improved understanding of the economic development process, and innovation's role within that process. Dataset development has a key role to play.

9.2. Datasets

Few international econometric studies have used datasets that provide a broad view of the practices within firms. Where such studies exist (*e.g.* Spanos and Lioukas 2001; Bloom *et al.* 2005), the datasets used would not meet the exacting standards of an official statistical agency (primarily because of small sample sizes and/or low response rates). New Zealand policy agency requirements for a more sophisticated understanding of firm practices and performance led, in 2001, to the introduction of the Business Practices Survey (BPS), which included questions on strategy, customer and supplier relations, HRM, benchmarking and quality control, together with

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(self-reported) performance metrics.[4] The survey was designed primarily on the basis of an understanding of the management, marketing and economics literatures, with a limited number of questions on innovation (Knuckey *et al.*, 2002).

Econometric research using the BPS dataset produced findings that were consistent with the importance of the business practices outlined in Section 9.1. Behaviours that were shown to be particularly important included R&D, HRM and marketing (Fabling and Grimes, forthcoming). Reinforcing the arguments above, traditional science and technology (S&T) indicators were found to signal firm success, but so too were activities underlying "non-technological" innovation, such as investment in market development or organizational improvement.[5] Importantly, it was seldom the case that better-performing firms engaged only in technological innovation. The unique aspect of this research lies entirely in the survey design, which allows the contribution of specific business practices to be isolated.

In 2003, Statistics New Zealand (SNZ) ran a full innovation survey (SNZ 2004). To date, this dataset has not been used for microeconometric research, and it was decided in 2005 that the way forward for innovation measurement in New Zealand was an integrated collection approach. The resulting Business Operations Survey (BOS) has a three-part modular survey design, with one module focused on firm characteristics and performance (both quantitative and qualitative measures), and two other modules examining business practices and outcomes. Although the survey is conducted annually, there is rotation of content, yielding annual firm performance data with alternating biennial data on innovation and business use of ICT (Figure 9.3). The modular approach has been adopted for two primary purposes: to cope with respondent load, driven by increasing end-user needs; and to allow specific policy-relevant data to be collected on an ad hoc basis – using a "contestable" third module – without the need for a full stand-alone survey to be administered. The survey's research potential is increased by the incorporation of a longitudinal sub-sample and by the planned linkage of the BOS to administrative (tax) firm performance data.

4. This survey had a predecessor in the New Zealand Manufacturing Business Practices Survey. As the name suggests, that survey had a narrow industry cover, and the questions asked reflected this (Knuckey, Leung-Wai and Meskill 1999).

5. Additionally, many practices appeared *not* to be significantly related to firm performance.

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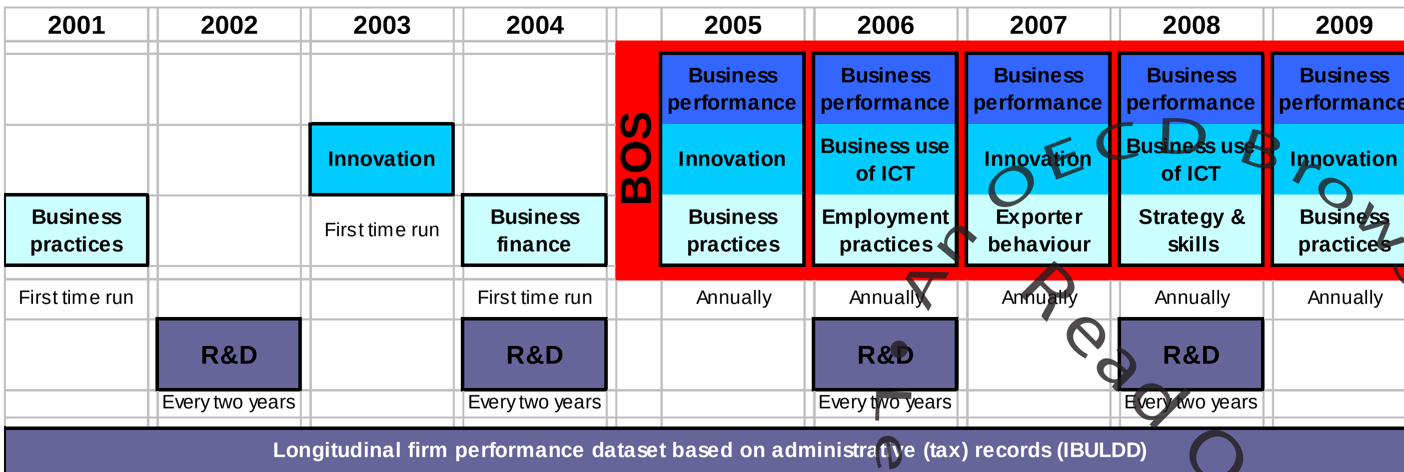
Figure 9.3. Business Operations Survey (BOS) modular design



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The BOS design process has presented SNZ and policy agencies with an opportunity to bring additional perspectives on firm performance into the process.[6] As a result of changes to the innovation data collection, SNZ has produced economy-wide estimates of product, process, organizational and marketing innovation, following the guidelines of the revised *Oslo Manual* (OECD/Eurostat 2005; SNZ 2006).

The BOS is sampled by two-way stratification on rolling mean employment (RME) and, predominantly two-digit, industry. The 2005 survey was mailed to 6 979 live firms, and a total of 5 595 usable responses were returned (80.2% response rate). These observations were weighted to represent the population of 34,760 private, economically significant firms in New Zealand with six or more RMEs in all industries excluding Government Administration and Defence; Libraries, Museums and the Arts; and Personal and Other Services.

Two types of analysis are presented in this chapter.

Section 9.3 presents population statistics and regressions for the BOS cross-section,[7] omitting Electricity, Gas and Water Supply, and Sport and Recreation industries. This had the effect of reducing the sample size by 111 firms and the population size by 499 (1.4%), but had the advantage of putting the BOS industry coverage on a consistent basis with the BPS (allowing easier comparison of the cross-section results with the panel results presented in Section 9.4).[8]

In 2005, the contestable third module of the BOS was constructed to replicate the business practice measurement in the BPS. Section 4 reports results for the panel of 1,285 firms in both the BPS and the BOS. This number constitutes 46.6% of BPS responses, which is high given that the BOS did not purposively survey surviving BPS respondents.[9] However,

6. The main areas of improvement in the BOS come through the following: incorporating advances in the study of innovation; using feedback from BPS research as to which behaviours seemed most important; bringing more quantitative discipline to the measurement of firm performance; and incorporating the growing international understanding of the role of ICTs as the latest in a series of general-purpose technologies.

7. All analyses in Section 3 used population weights and accounted for the survey design.

8. While both survey populations had a minimum employment cut-off of six, the basis for measuring employment shifted from full-time equivalents (FTEs) to RMEs. The main conceptual differences are: FTEs include working proprietors; RMEs are calculated on a head-count basis, while FTEs count part-time workers as 0.5 FTE; and FTEs are February snapshots, while RMEs are an average of monthly counts. The net effect on the comparability of the BPS and BOS populations is unknown; however, the two employment measures are strongly correlated in the panel.

9. The BOS 2005 was mailed to 55% of BPS respondents and had an 84% response rate.

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there was attrition in BPS respondents between 2001 and 2005, and there is some indication that this panel may be biased in favour of better-performing firms. In particular, the primary reasons for non-availability for selection in the panel were firms no longer being on the statistical frame or employment dropping below the population threshold.[10] This bias manifests itself through the greater incidence of some "high-performance" practices in the panel relative to that in the BPS population. Given the importance of this issue, it is revisited in Section 9.4. In this chapter, no effort has been made to compensate for this bias – a fact to remember when interpreting Section 9.4 results.[11]

9.3. Innovation results, 2005

This section first compares and contrasts different innovation measures (across both practices and outcomes) within the BOS 2005 cross-section. This is the first research use of these data, and the analysis is, naturally, exploratory. Since this chapter is partly concerned with reporting the results of the expanded innovation collection format (*i.e.* the introduction of two "new" innovation types), firms that had *successfully* innovated were divided into three distinct groups: those that had introduced product and/or operational process innovations only (PP); those that had introduced organizational/managerial process and/or marketing method innovations only (OM); and those that had introduced a combination of PP and OM innovations (COMBO).[12] Given the prior discussion, it should be noted that the breakdown into innovation groups is inconsistent with our advocated holistic view of the firm; it was done purely for ease of exposition and not for conceptual reasons.

10. SNZ's statistical frame tracks legal units over time, so that attrition from the frame should not be assumed always to be a trait of poor-performing firms.

11. The Section 4 panel results are reported on an unweighted basis. That is, these data are not treated as representative of any wider population.

12. Firms that had not successfully completed any innovation in the previous two years (NON) act as the reference group. This diverse group of firms was made up of those that were attempting to innovate but had not completed an innovation; those that had attempted, but then abandoned, an innovation; and those that had not attempted to innovate in the reference period.

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Table 9.1. Innovation rates and relationships between innovation outcomes, 2005

Headline innovation rates (2yr):	Number	**RATE**	Of which also: Introduced new products	Introduced new operational processes	Introduced new organizational/ managerial processes	Introduced new marketing methods	Of which also: Ongoing product innovation activities	Ongoing operational process innovation activities	Ongoing organizational/managerial process innovation activities	Ongoing marketing method innovation activities
<u>Introduced</u> new products	7852	**22.9%**	100.0%	44.2%	47.8%	48.4%	30.3%	25.1%	20.6%	23.1%
<u>Introduced</u> new operational processes	7066	**20.6%**	49.1%	100.0%	63.5%	52.6%	26.2%	31.2%	24.3%	21.3%
<u>Introduced</u> new organizational/managerial processes	9124	**26.6%**	41.2%	49.2%	100.0%	51.4%	25.6%	29.8%	28.9%	25.9%
<u>Introduced</u> new marketing methods	8147	**23.8%**	46.6%	45.6%	57.6%	100.0%	26.3%	24.5%	21.3%	27.5%

Innovation groups (2yr):	Number	**RATE**	Of which also: Ongoing PP innovation activities	Ongoing OM innovation activities	Ongoing COMBO innovation activities	No ongoing innovation activities
PP: <u>Introduced</u> product AND/OR operational process innovations ONLY	4799	**14.0%**	9.6%	4.0%	19.9%	66.5%
OM: <u>Introduced</u> organizational/managerial process AND/OR marketing method innovations ONLY	3669	**10.7%**	4.6%	8.2%	18.5%	68.6%
COMBO: <u>Introduced</u> combination of "technological" & "non-technological" innovations	7782	**22.7%**	8.4%	7.0%	36.0%	48.6%
NON: No innovation <u>introduced</u> over the period	18011	**52.6%**	0.9%	2.3%	4.2%	92.7%
	34261	**100.0%**				

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Table 9.1 presents innovation rates and the innovation groups. The top section of the table shows overall rates for the four innovation outcomes and, to the right, rates of successful (and ongoing attempts at) innovation conditional on having innovated on another dimension.[13] For example, of those firms that had successfully introduced new operational processes, 63.5% had also introduced new organizational/managerial processes. These results support the motivating hypothesis of this chapter: technological progress does not operate independently of wider practices within the firm. Applying the innovation group definitions above emphasizes this point. The bottom section of the table shows that the COMBO group (*i.e.* firms that had introduced a combination of "technological" and "non-technological" innovations) had by far the largest population among the innovation groups. Figure 9.4 puts these results in the context of economy-wide innovation by comparing innovation in 2003 and 2005. Little attention should be paid to overall rates, because both populations had to be adjusted to achieve comparability, and because the innovation reference periods were different. The important point to draw from this figure is that the 2003 results miss the complexity of the innovation story for a significant proportion of product and operational process innovators.

The distinction between PP and OM innovation groups is itself unclear, since over one-fifth of the members of each of these groups considered they were ongoing innovators on the other dimension (bottom right of Table 9.1). These last data suggest a potential mislabelling of the innovation groups as "distinct." However, it was preferable to specify subsequent regressions with outcomes on the left-hand side and activities on the right-hand side (despite the obvious problem of whether causality can be asserted in this contemporaneous relationship). The admission that the groupings violated the advocated holistic approach had already been made. Firms crossing the artificially imposed boundaries only emphasize this latter point.[14]

13. Innovation rates were measured over a two-year time frame to align with the frequency of the BOS innovation data collection.

14. The robustness of this decision was tested by the construction of two alternative dependent variables for model (1) in Table 9.2. First, the innovation groups were expanded to include ongoing innovators; and, second, innovations were counted and an ordered probit regression performed. Both specifications showed similar bulk features (signs and significance of independent variables) to those of the preferred model.

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Figure 9.4. Headline innovation outcome comparison, 2003 and 2005 (consistent population)

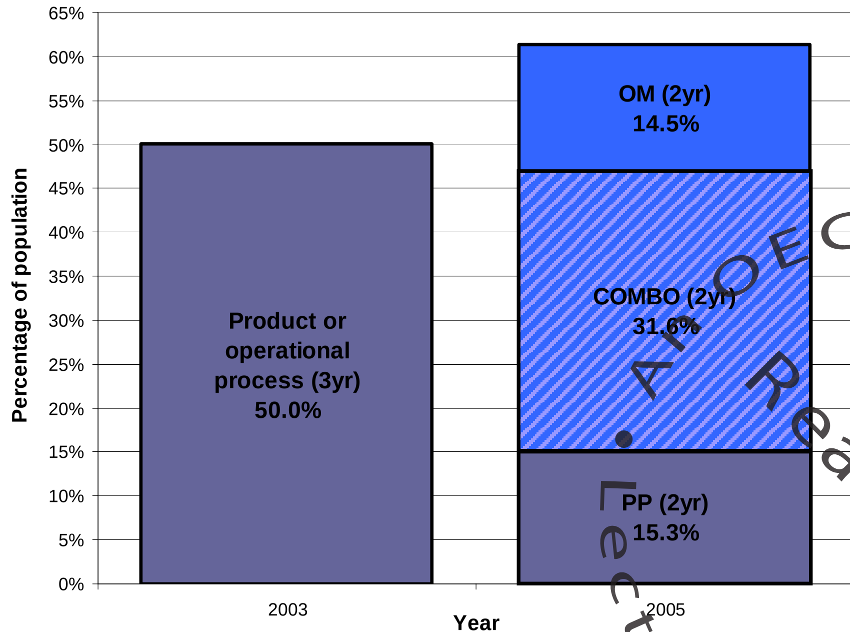

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Figure 9.5. Innovation activities, 2005 (BPS-consistent industry coverage)

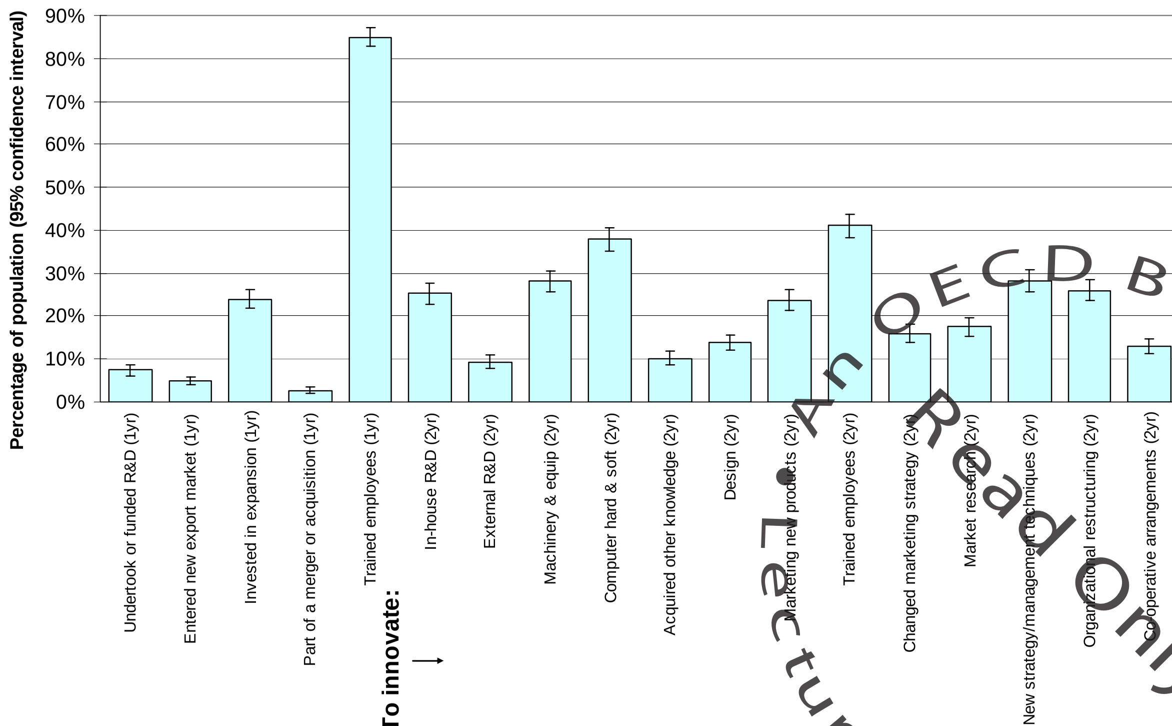

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Figure 9.6. Sources of ideas/information for innovation, 2005 (BPS-consistent industry coverage)

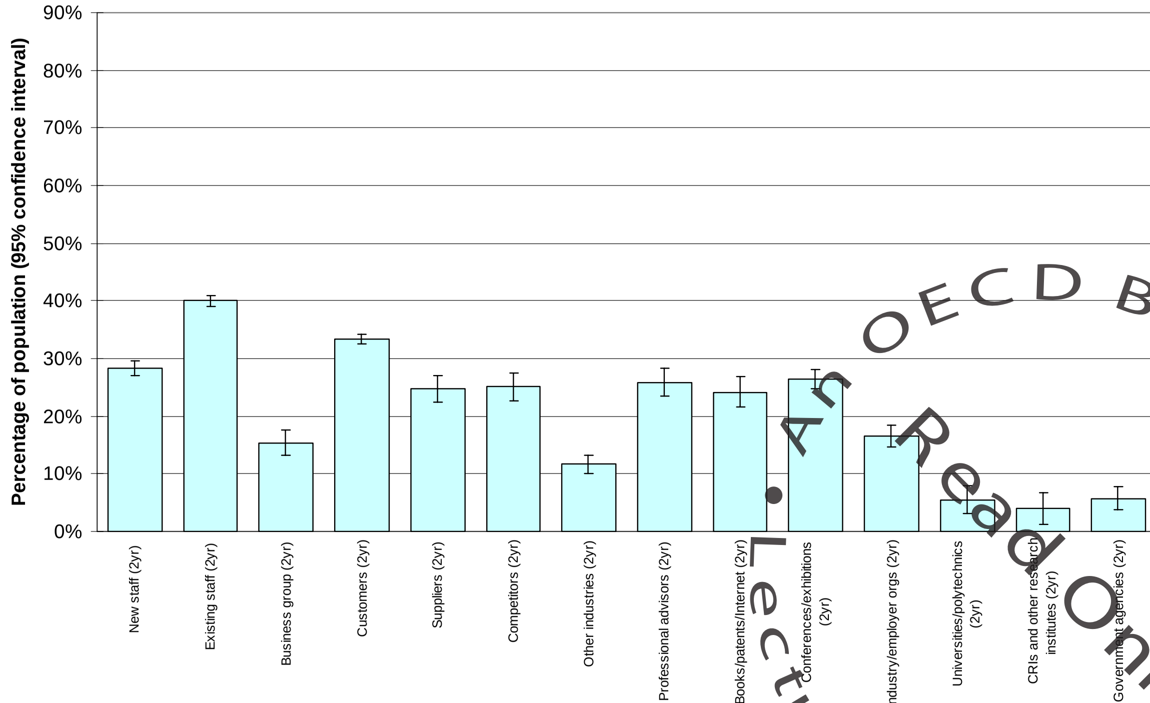

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Figure 9.5 shows overall participation rates in innovation activities measured in the BOS 2005, while Figure 9.6 shows sources of ideas for innovation. There was significant variation in the rates of business uptake of these practices: general training of employees was conducted by 85% of firms, while mergers and acquisitions (M&A) activity affected less than 3% of the population. The question to be asked is: What is the contemporaneous relationship between innovation activities and outcomes? To answer this question, a series of multinomial probit regressions of the innovation groups on firm characteristics and various combinations of innovation activities was conducted (Table 9.2).[15] The coefficients in the table offer two interpretations. First, they indicate whether the characteristic, practice or source of information was more or less likely to be associated with the innovation group that heads the column the coefficient is in (relative to the NON group). A p-value under each coefficient indicates the statistical significance of this interpretation. Second, the coefficients can be compared, by looking across a row (within a model), to see whether an independent variable was more likely to be associated with some successful innovation groups than with others. A supplementary test of the equivalence of the OM and PP coefficients indicated whether the characteristic, practice or source of information was significantly more likely to be related to one of these outcomes (p-values for these tests are not reported, but significant differences at the 5% level are denoted in the table by bold coefficients).

Firm size, export intensity and ODI all have significantly positive coefficients in model (1), but these results are not robust to the inclusion of firm practices. FDI was related to innovation outcomes across all specifications, and it was more likely to be associated with PP innovation than with OM innovation. Subsidiary firms were significantly less likely to be innovative, perhaps because of a division of responsibilities within the business group (the model (3) effect of the business group as a source of ideas would support this hypothesis). Firm age was not significant in any of the regressions. It may be that the simple model specified was not appropriate, or that other variables, particularly firm size, were picking up any life-cycle effect.

15. Included in firm characteristics are: firm size (in logs); age (in logs); export intensity (percentage of total sales); foreign direct investment (FDI) intensity (proportion of firm ownership from overseas); outward direct investment (ODI) indicator (whether the firm had offshore interests); subsidiary firm (whether the firm was in a business group, but not the group leader); and industry (division-level Australian and New Zealand Standard Industrial Classification (ANZSIC) 1993 dummies). Industry dummies are not reported in most tables. These dummies are jointly significant in all specifications.

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Table 9.2. Contemporaneous relationship between innovation activities and outcomes *(see notes p. 157)*

	Panel (1)			Panel (2)			Panel (3)			Panel (4)		
	OM	**PP**	**COMBO**	**OM**	**PP**	**COMBO**	**OM**	**PP**	**COMBO**	**OM**	**PP**	**COMBO**
ln(RME)	0.213** [0.000]	0.201** [0.000]	0.238** [0.000]	0.009 [0.893]	-0.017 [0.817]	-0.082 [0.247]	-0.017 [0.804]	0.055 [0.409]	0.005 [0.946]	-0.025 [0.727]	0.009 [0.898]	-0.079 [0.272]
ln(age)	0.011 [0.879]	0.003 [0.962]	-0.084 [0.206]	0.041 [0.597]	0.038 [0.610]	-0.066 [0.446]	0.061 [0.450]	-0.009 [0.909]	-0.055 [0.562]	0.051 [0.532]	-0.006 [0.936]	-0.080 [0.380]
Export intensity	0.004* [0.032]	0.009** [0.001]	0.007** [0.000]	0.003 [0.242]	0.006 [0.072]	0.003 [0.323]	0.004 [0.155]	0.007* [0.036]	0.007** [0.008]	0.004 [0.221]	0.005 [0.169]	0.004 [0.215]
Foreign direct investment (FDI) intensity	0.002 [0.487]	0.006** [0.009]	0.004* [0.039]	0.004 [0.194]	**0.009**** **[0.001]**	0.007* [0.020]	0.003 [0.233]	**0.009**** **[0.003]**	0.006* [0.026]	0.005 [0.084]	**0.011**** **[0.000]**	0.008** [0.006]
Outward direct investment (ODI) indicator	0.516* [0.031]	0.578** [0.005]	1.277** [0.000]	0.092 [0.808]	0.233 [0.532]	0.774 [0.119]	-0.149 [0.646]	-0.117 [0.703]	0.535 [0.139]	-0.089 [0.804]	-0.073 [0.842]	0.557 [0.229]
Subsidiary firm	-0.317* [0.048]	-0.383** [0.007]	-0.281* [0.027]	-0.610* [0.037]	-0.579* [0.023]	-0.588 [0.063]	-0.693* [0.010]	-0.801** [0.003]	-0.665* [0.014]	-0.691* [0.014]	-0.754** [0.004]	-0.629* [0.032]
Entered new export market (1yr)				0.706* [0.014]	0.310 [0.267]	1.017** [0.000]				**0.561*** **[0.048]**	0.048 [0.860]	0.781** [0.004]
Invested in expansion (1yr)				0.018 [0.921]	0.061 [0.691]	0.209 [0.249]				0.056 [0.740]	0.123 [0.421]	0.269 [0.126]
R&D intensity (1yr)				-0.043 [0.053]	-0.034* [0.033]	-0.045** [0.003]				-0.029 [0.142]	-0.025 [0.063]	-0.037** [0.008]
Share of in-house R&D (1yr)				0.004 [0.363]	**0.012** **[0.053]**	0.011* [0.016]				0.001 [0.679]	**0.010*** **[0.020]**	0.009** [0.005]
Part of a merger or acquisition (1yr)				-0.023 [0.946]	-0.500 [0.278]	0.150 [0.723]				-0.209 [0.524]	-0.710 [0.051]	-0.017 [0.966]
Trained employees (1yr)				-0.494* [0.014]	-0.103 [0.645]	0.417 [0.067]				-0.538* [0.016]	-0.150 [0.505]	0.367 [0.127]

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Table 9.2. Contemporaneous relationship between innovation activities and outcomes *(continued)*

	Panel (1)			Panel (2)			Panel (3)			Panel (4)		
	OM	PP	COMBO	OM	PP	COMBO	OM	PP	COMBO	OM	PP	COMBO
To innovate (2yr):												
Machinery and equipment				0.600*	**0.973****	0.711**				0.573*	0.922**	0.690**
				[0.011]	**[0.000]**	[0.002]				[0.015]	[0.000]	[0.003]
Computer hardware and software				0.970**	0.764**	1.178**				0.633**	0.363	0.845**
				[0.000]	[0.000]	[0.000]				[0.003]	[0.085]	[0.000]
Acquired other knowledge				-0.018	-0.064	0.216				0.097	0.111	0.386
				[0.950]	[0.836]	[0.483]				[0.752]	[0.733]	[0.232]
Design				0.570*	0.834**	0.722**				0.467	0.725**	0.588*
				[0.023]	[0.001]	[0.003]				[0.056]	[0.002]	[0.011]
Marketing new products				0.420	**0.932****	1.195**				0.259	**0.770****	1.066**
				[0.091]	**[0.000]**	[0.000]				[0.245]	**[0.001]**	[0.000]
Trained employees				1.410**	1.423**	1.065**				0.876**	0.893**	0.555**
				[0.000]	[0.000]	[0.000]				[0.000]	[0.000]	[0.008]
Changed marketing strategy				**0.484**	-0.162	0.735*				**0.464**	-0.237	0.635*
				[0.098]	[0.605]	[0.018]				**[0.075]**	[0.405]	[0.027]
Market research				0.331	0.451	0.338				0.016	0.080	0.008
				[0.216]	[0.131]	[0.193]				[0.952]	[0.771]	[0.976]
New strategy/management techniques				**0.824****	-0.089	0.812**				**0.429***	-0.479*	0.479*
				[0.000]	[0.701]	[0.000]				**[0.049]**	[0.035]	[0.035]
Organizational restructuring				**0.708****	-0.006	0.656**				**0.577***	-0.027	0.568*
				[0.005]	[0.980]	[0.009]				**[0.024]**	[0.909]	[0.017]
Co-operative arrangements				0.970**	1.103**	1.419**				0.697	0.728*	1.089**
				[0.008]	[0.001]	[0.000]				[0.055]	[0.022]	[0.002]

continued…

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Table 9.2. Contemporaneous relationship between innovation activities and outcomes *(continued)*

	Panel (1)			Panel (2)			Panel (3)			Panel (4)		
	OM	PP	COMBO	OM	PP	COMBO	OM	PP	COMBO	OM	PP	COMBO
Sources of innovation ideas (2yr):												
New staff							**0.420**	-0.546*	0.276	**-0.013**	-0.814**	-0.207
							[0.059]	[0.012]	[0.201]	**[0.954]**	[0.000]	[0.334]
Existing staff							1.692**	2.097**	1.697**	1.222**	**1.698****	1.085**
							[0.000]	[0.000]	[0.000]	[0.000]	**[0.000]**	[0.000]
Business group							1.008**	0.890*	0.936**	0.282	0.302	0.044
							[0.005]	[0.014]	[0.005]	[0.358]	[0.306]	[0.878]
Customers							0.425*	0.512*	0.767**	0.014	0.269	0.313
							[0.044]	[0.018]	[0.000]	[0.949]	[0.404]	[0.154]
Suppliers							0.249	0.167	0.234	0.002	-0.104	-0.140
							[0.252]	[0.447]	[0.292]	[0.994]	[0.655]	[0.526]
Competitors							0.405	0.505*	0.482*	0.290	0.289	0.293
							[0.091]	[0.030]	[0.036]	[0.235]	[0.215]	[0.212]
Other industries							-0.253	-0.049	0.223	-0.598*	-0.320	-0.203
							[0.440]	[0.883]	[0.515]	[0.049]	[0.287]	[0.509]
Professional advisors							**0.789****	0.451*	0.608**	0.602**	0.396	0.505*
							[0.000]	[0.033]	[0.007]	[0.007]	[0.076]	[0.030]
Books/patents/Internet							0.390	0.305	0.346	0.133	0.224	0.048
							[0.103]	[0.146]	[0.103]	[0.586]	[0.328]	[0.833]
Conferences/exhibitions							0.670**	0.794**	0.853**	0.383	0.471*	0.477*
							[0.004]	[0.000]	[0.000]	[0.105]	[0.039]	[0.044]
Industry/employer organizations							0.491*	0.211	0.430	0.197	0.102	0.059
							[0.040]	[0.375]	[0.103]	[0.444]	[0.681]	[0.822]
Universities/polytechnics							-0.034	0.389	0.344	-0.378	0.047	-0.074
							[0.924]	[0.232]	[0.295]	[0.241]	[0.883]	[0.813]

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Table 9.2. Contemporaneous relationship between innovation activities and outcomes *(continued)*

	Panel (1)			Panel (2)			Panel (3)			Panel (4)		
	OM	PP	COMBO	OM	PP	COMBO	OM	PP	COMBO	OM	PP	COMBO
Sources of innovation ideas (2yr) *(cont'd)*:												
CRIs and other research institutes							-0.307 [0.429]	**0.403** **[0.290]**	-0.240 [0.522]	-0.497 [0.175]	**0.307** **[0.412]**	-0.557 [0.138]
Government agencies							-0.235 [0.501]	-0.710 [0.056]	0.041 [0.902]	-0.176 [0.619]	-0.743 [0.053]	0.109 [0.757]
		NON	96.8%		NON	94.0%		NON	94.7%		NON	94.5%
		OM	0.0%		OM	30.5%		OM	19.2%		OM	34.7%
		PP	0.1%		PP	32.7%		PP	22.7%		PP	39.3%
		COMBO	13.6%		COMBO	70.6%		COMBO	65.5%		COMBO	70.5%
			54.0%			73.2%			69.8%			74.8%

Notes: All models are multinomial probits with innovation group as the dependent variable (NON is the base outcome). Regressions contain industry dummies (division-level ANZSIC, coefficients not shown). Asterisks denote significance at the 5% (*) and 1% (**) levels (two-sided test – robust p-values in square brackets below coefficients). Bold coefficients indicate significant (5% level) difference between PP and OM innovator coefficients (larger of the two highlighted). Proportions of each innovation group accurately predicted are shown below the table.

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At the bottom of each model are the proportions of accurately predicted innovation groups. Model (1) is poor at identifying innovators of any type.[16] The model becomes better at discerning successful innovators once innovation activities and/or sources of information are introduced. Part of the increase in the overall prediction rate from the first model (54%) to the last (74.8%) is likely to be due to the routing in the innovation module of the survey.[17] However, the way in which the model allocates innovators to innovation groups has also improved, suggesting that the practice-inclusive models *are* adding explanatory power over and above the routing effect.

It is evident from model (4) that most sources of innovation ideas were not individually significantly related to innovation outcomes, the strongest positive effect coming from existing staff (whereas new staff were negatively related to PP innovation outcomes). In contrast, most innovation practices were significantly related to innovation outcomes (bearing in mind the caveat around these significance tests). To highlight just a few points: innovation-specific employee training was important, whereas general training was not (general training being pervasive and therefore a common characteristic of non-innovators); the newly measured innovation activities of changed marketing strategy, new strategy/management techniques and organizational restructuring had a significantly higher relationship with OM than with PP innovation;[18] marketing new products was a property of PP innovation (perhaps suggesting that existing marketing methods were more commonly used to introduce new products); higher shares of in-house R&D were of greatest importance to PP innovators; and the contemporaneous relationship of R&D intensity to innovation outcomes was, if anything, negative. Given the existing literature on the role of R&D in innovation, this last observation should raise concerns about causality and the importance of

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16. A randomized allocator would, on average, score 25% on this measure. A model that does not predict any innovators would score 53% (*i.e.* the rate of non-innovators).

17. Respondents that did not identify themselves as successful, ongoing or ceased innovators were routed past the innovation questions used in this analysis. Since the innovation activity and "source of information" questions were asked in relation to "trying to innovate," zeroes were assigned as the responses to these routed questions. While logically appropriate, the imposition of an exact relationship for roughly half the population strengthens the apparent statistical association between the activities and outcomes (and therefore risks imposing the result that is to be tested).

18. While coefficient signs consistent with intuition support the idea that the model was appropriate, an alternative (or additional) interpretation might be that the questionnaire led respondents to the "appropriate" answers on innovation activity. Examining the direct relationship between quantitative firm performance and innovation activities, or the lagged effect of these activities on outcomes, may shed light on this issue.

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considering lags between practices and outcomes.[19] These concerns lead to a consideration of the BPS-BOS panel.

9.4. Panel results

This section seeks to relate general business practices in 2001 to innovation outcomes in 2005. A measure of firm practices (excluding innovation activities) was constructed from a subset of questions for which a concordance could confidently be mapped across the BPS and BOS surveys (Table 9.3 lists the subject areas covered).[20] Specifically, self-reported "high" relative productivity (a binary) was regressed on population-weighted BPS practices, and the predicted probabilities generated by this model were used as the measure of management practices in both 2001 and 2005 (*i.e.* for the 2005 management practice index, 2001 model coefficients with 2005 variable values were used).[21]

Table 9.3. Questions used in the management practice index

Description	BPS	BOS
Clear vision or mission	Q2.3	C7
Promoted set of company values	Q2.4	C8
Procedures for customer complaints	Q3.1	C10
Non-sales staff in contact with customers	Q3.2	C11
Measure customer satisfaction	Q3.3	C12
Customer involvement in product development	Q3.4	C13
Systems to measure supplier quality (binary)	Q4.1	C14
Supplier involvement in process improvement	Q4.2	C15
Delegation authority to handle supplier problems	Q4.3	C17

(continued…)

19. Another potential explanation is that the choice of R&D question was wrong. This was tested by the introduction of the innovation module R&D indicators into the model (2) specification, with the following effects: R&D intensity remained significantly negative with almost identical coefficients; the p-values on the in-house R&D share coefficient became large and the in-house R&D indicator was significantly positive for PP and COMBO innovation (suggesting multicollinearity); and the external R&D indicator was negative but insignificantly different from zero.
20. Innovation activities were deliberately excluded from this list, so that their additional impact on innovation outcomes could be tested.
21. This model ignores the fact that "good" management practices may be industry- or size-specific.

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Table 9.3. Questions used in the management practice index *(continued)*

Description	BPS	BOS
Formal performance reviews (binary)	Q5.2	C26
Performance pay schemes (binary)	Q5.3	C27
General employee training (binary)	Q5.5	C28
Health and safety management processes	Q5.6	C31
Staff involvement in product/process problem identification	Q6.1	C33
System for information storage & retrieval	Q7.1	C18
Systematic benchmarking against other firms	Q7.2	C21
Use of various measures to assess performance	Q7.4	C20
Monitoring competitors' products	Q7.5	C22
Closeness of core equipment to "frontier"	Q9.7	A45

Note: For questions with multiple response categories, each category response was entered as a separate binary variable. Where applicable, the “don’t know” category of each question was dropped (to avoid perfect multi-collinearity); failing that, the “no” category was dropped.

The issue of panel bias needs to be revisited before the properties of this index are discussed. In Table 9.4, a binary of whether a firm was in the panel was regressed on the 2001 (population-weighted) characteristics of firms in the BPS dataset, and on survival on the sampling frame.[22] This latter variable was, naturally, a critical determinant of the panel composition. Since survival on the frame captures the attrition effect, the importance of firm size should be interpreted as being related to sampling, specifically by reducing the probability of dropping below the BOS firm size threshold and by increasing the probability that the firm will be in a stratum with a higher sampling proportion. To some extent, bias is also suggested by the 2001 practices and outcomes of firms in the panel. Testing across product and process innovation outcomes, innovation practices and the management practice index shows that the panel has a significantly larger proportion of firms that were marketing the introduction of new products ($p = 0.020$) and that were well managed ($p = 0.000$), as measured by the management practice index. This latter effect is demonstrated in Figure 9.7, where the distribution of the 2001 management practices of the panel relative to that of the BPS population is shown.

22. Some control variables in 2005 were unavailable in 2001 (ODI and subsidiary) and others (FDI and export) were binaries instead of intensities. While detail was lost, there was a very strong relationship between 2001 and 2005 controls, reflecting the expectation that these characteristics should display some persistence. Similarly, some of the practice categories were slightly different between the BOS and the BPS. These differences are reflected in Table 9.6 variable names, where applicable.

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Table 9.4. Firm characteristics favouring selection in the panel

	In panel
ln(FTE)	0.297**
	[0.000]
ln(age)	0.157
	[0.107]
Export indicator	0.110
	[0.255]
Foreign direct investment (FDI) indicator	0.012
	[0.930]
Mining and quarrying (ANZSIC division B)	0.559*
	[0.029]
Manufacturing (ANZSIC division C)	-0.153
	[0.294]
Construction (ANZSIC division E)	0.825**
	[0.000]
Wholesale trade (ANZSIC division F)	0.744**
	[0.000]
Retail trade (ANZSIC division G)	0.890**
	[0.000]
Accommodation, cafes and restaurants (ANZSIC division H)	-0.145
	[0.531]
Transport and storage (ANZSIC division I)	0.599**
	[0.003]
Communication services (ANZSIC division J)	0.391
	[0.157]
Finance and insurance (ANZSIC division K)	0.460*
	[0.022]
Property and business services (ANZSIC division L)	0.808**
	[0.000]
Education (ANZSIC division N)	1.014**
	[0.000]
Health and community services (ANZSIC division O)	0.677**
	[0.002]
Cultural and recreational services (ANZSIC division P)	0.634*
	[0.010]
Survived	1.913**
	[0.000]
Constant	-3.461**
	[0.000]
	R^2: 0.281

Note: Probit regression with selection in the panel as the dependent variable. Asterisks denote significance at the 5% (*) and 1% (**) levels (two-sided test – robust p-values in square brackets below coefficients).

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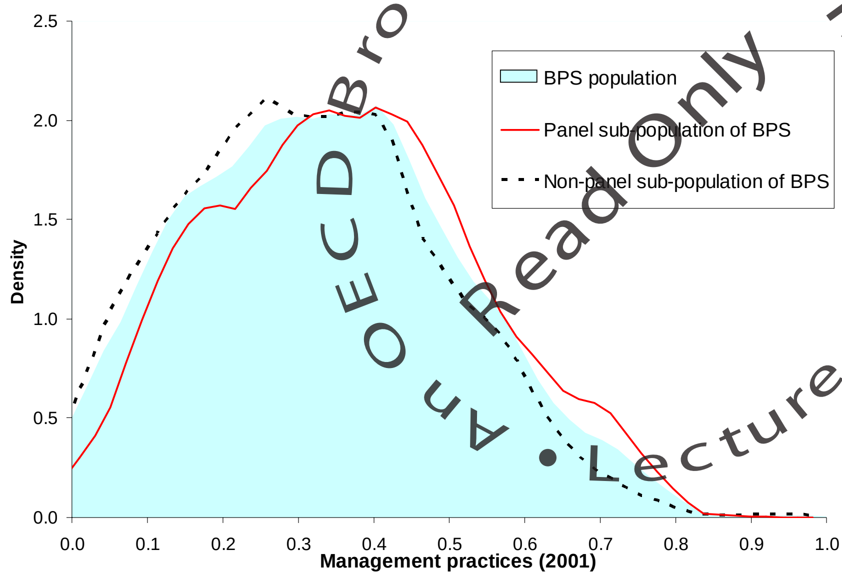
Figure 9.7. Management practices of panel relative to those of the BPS population, 2001



With this potential bias borne in mind, two common-sense tests were performed on the management practice index. First, the persistence of practices over time was examined, and it was noted that there was a general increase in the index from 2001 to 2005 (Figure 9.8).[23] While changes in practices were quite diverse, prior practices played an important role in explaining subsequent practices (model (1) of Table 9.5). Second, model (2) of Table 9.5 confirms that firms that reported organizational/managerial innovation over the period 2003–2005 also experienced changes in practices, as measured by the change in the index between 2001 and 2005. Taken together, the regressions in Table 9.5 suggest that the conservative approach taken to variable concordance was satisfactory, and that what the management practice index was measuring was consistent with the respondents' sense of how their firm had changed. Model (2) could also be considered a useful "reality check" on the respondents' interpretation of the organizational/managerial innovation question.

23. The continuous line in Figure 9.8 shows how the density of management practices changed. There was a net decline in the number of firms with scores between 0.2 and 0.5, with most of the net increase occurring at index values above 0.5.

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Figure 9.8. Changes in management practices, 2001–2005

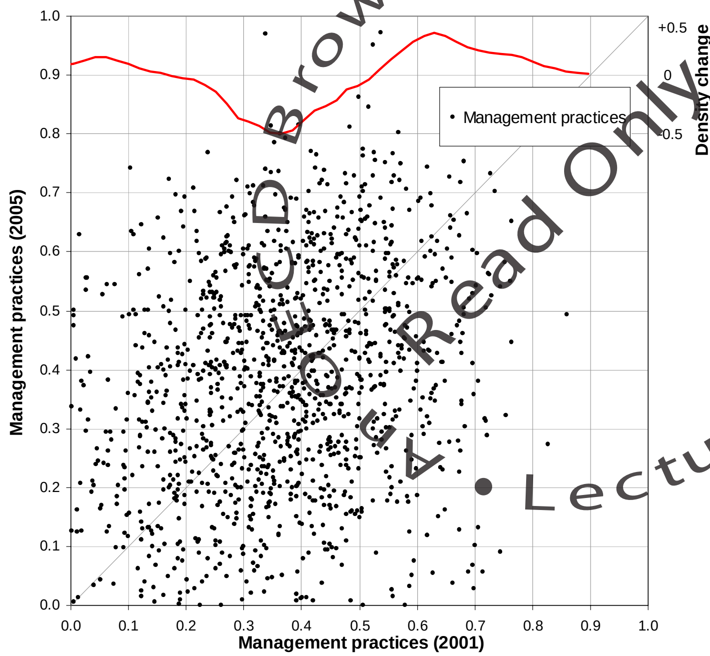

Table 9.5. Tests of the plausibility of the management practice index

	Panel (1) Management practices (2005)	Panel (2) Organizational/ managerial innovation (2005)
ln(FTE)	0.021**	0.208**
	[0.000]	[0.000]
ln(age)	0.005	-0.041
	[0.485]	[0.447]
Export indicator	-0.006	0.026
	[0.588]	[0.766]
Foreign direct investment (FDI) indicator	0.001	0.149
	[0.972]	[0.178]
Management practices (2001)	0.232**	
	[0.000]	
Change in management practices		0.537**
		[0.002]
	R^2: 0.111	R^2: 0.054

Note: Model (1) is a linear regression with the management practice (2005) index as the dependent variable. Model (2) is a probit with reported organizational/managerial innovation as the dependent variable. Both regressions contain industry dummies (division-level ANZSIC, coefficients not shown). Asterisks denote significance at the 5% (*) and 1% (**) levels (two-sided test – robust p-values in square brackets below coefficients).

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Using the management practice index, a two-stage test (Table 9.6) addressed the question: What impact did 2001 business practices have on 2005 innovation outcomes? Initially, the impact of innovation practices and sources of information on innovation groups was tested. Then, the measure of how well managed the firm was in 2001 was introduced to see what impact this additional explanatory variable may have had. Model (1) reveals that very few innovation activities were significantly linked to positive future innovation outcomes. Consistent with concerns about the potential for returns to R&D being lagged, both in-house R&D and engagement with universities/polytechnics were now positively associated with innovation, whereas contemporaneously they were not. Marketing new products stands out as being positively associated with innovation outcomes, both contemporaneously and over time. Other innovation activities – investment in machinery and equipment, industrial design, and innovation-related employee training – show no longer-term relationship with innovation, but all had strong positive contemporaneous relationships (Table 9.2), perhaps suggesting that the intent of these activities was to enable the production of current innovations rather than to be investments in the future innovative capacity of the firm.

Table 9.6. Lagged effect of practices on innovation outcomes

	Panel (1)			Panel (2)		
	OM	PP	COMBO	OM	PP	COMBO
ln(FTE)	0.132*	0.020	0.157**	0.130*	0.022	0.149**
	[0.029]	[0.748]	[0.005]	[0.031]	[0.729]	[0.009]
ln(age)	0.058	0.119	0.010	0.061	0.119	0.018
	[0.509]	[0.193]	[0.902]	[0.492]	[0.194]	[0.821]
Export indicator	-0.124	0.034	0.160	-0.120	0.032	0.183
	[0.419]	[0.818]	[0.235]	[0.435]	[0.829]	[0.177]
Foreign direct investment (FDI) indicator	-0.041	-0.052	0.092	-0.046	-0.052	0.082
	[0.842]	[0.793]	[0.606]	[0.824]	[0.793]	[0.643]
To innovate (1yr):						
In-house R&D	-0.050	0.130	0.471**	-0.054	0.134	0.453**
	[0.742]	[0.382]	[0.000]	[0.723]	[0.370]	[0.001]
External R&D	0.167	0.020	0.069	0.165	0.029	0.059
	[0.336]	[0.907]	[0.662]	[0.344]	[0.868]	[0.712]
Machinery and equipment	0.013	0.169	0.110	0.010	0.172	0.097
	[0.924]	[0.217]	[0.394]	[0.945]	[0.211]	[0.450]
Acquired other knowledge	-0.176	0.055	0.303	-0.182	0.056	0.286
	[0.368]	[0.765]	[0.063]	[0.354]	[0.761]	[0.079]

continued…

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Table 9.6. Lagged effect of practices on innovation outcomes *(continued)*

	Panel (1)			Panel (2)		
	OM	PP	COMBO	OM	PP	COMBO
Industrial design	0.006	0.282	0.018	0.003	0.301	-0.012
	[0.983]	[0.259]	[0.941]	[0.993]	[0.230]	[0.960]
Marketing new products	0.066	0.365*	0.397**	0.063	0.371**	0.380**
	[0.661]	[0.010]	[0.002]	[0.677]	[0.009]	[0.004]
Trained employees	0.240	0.062	0.191	0.231	0.063	0.168
	[0.086]	[0.658]	[0.142]	[0.097]	[0.655]	[0.199]
Sources of innovation ideas:						
Competitors	0.322	-0.064	0.080	0.313	-0.062	0.063
	[0.095]	[0.725]	[0.641]	[0.105]	[0.733]	[0.714]
NZ owners & associated firms	0.064	0.048	0.018	0.057	0.053	-0.002
	[0.642]	[0.727]	[0.884]	[0.679]	[0.702]	[0.986]
Overseas owners & associated firms	0.151	0.131	0.094	0.148	0.129	0.085
	[0.286]	[0.339]	[0.466]	[0.297]	[0.349]	[0.512]
Industry/employer organizations	-0.087	-0.049	-0.225	-0.092	-0.050	-0.247
	[0.533]	[0.731]	[0.082]	[0.513]	[0.725]	[0.056]
Research institutes & consultants	-0.144	-0.113	-0.096	-0.146	-0.113	-0.100
	[0.329]	[0.439]	[0.477]	[0.323]	[0.441]	[0.458]
Universities/polytechnics	0.086	0.365*	0.197	0.084	0.370*	0.194
	[0.607]	[0.030]	[0.197]	[0.615]	[0.029]	[0.206]
Books/conferences/exhibitions	-0.002	0.129	-0.016	-0.002	0.121	-0.006
	[0.990]	[0.434]	[0.917]	[0.990]	[0.465]	[0.968]
Professional advisors	-0.147	-0.464**	-0.095	-0.145	-0.465**	-0.081
	[0.308]	[0.002]	[0.475]	[0.315]	[0.002]	[0.539]
Trade New Zealand	0.323	-0.046	0.158	0.320	-0.044	0.141
	[0.157]	[0.836]	[0.415]	[0.161]	[0.844]	[0.466]
Technology New Zealand	-0.171	-0.190	-0.005	-0.169	-0.194	0.009
	[0.543]	[0.461]	[0.981]	[0.548]	[0.449]	[0.968]
Industry New Zealand	-0.262	0.109	0.148	-0.266	0.110	0.126
	[0.373]	[0.684]	[0.562]	[0.365]	[0.680]	[0.622]
Government departments	0.197	0.227	-0.090	0.197	0.222	-0.089
	[0.306]	[0.222]	[0.614]	[0.306]	[0.230]	[0.622]
Management practices (2001)				0.239	-0.141	0.896*
				[0.548]	[0.725]	[0.016]

	Panel (1)		Panel (2)
NON	93.5%	NON	91.8%
OM	0.6%	OM	0.6%
PP	3.8%	PP	4.2%
COMBO	35.5%	COMBO	35.8%
	54.5%		53.8%

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Model (2) introduces 2001 management practices. A twofold conclusion can be drawn: the initial endowment of management practices was good for COMBO innovation outcomes in 2005; and the introduction of the management variable had no substantial impact on the coefficients or significance of in-house R&D and marketing of new products. In other words, good management practices appear to provide an *additional* effect on future innovation outcomes.

9.5. Conclusion

How innovative are New Zealand firms? Based on the evidence presented here, it appears that they are more innovative than previously thought. What impact do these innovations have on firm performance? Nobody knows, but resources are being invested to find out. This chapter has attempted to give an idea of the questions that may now be answerable by the new data. Driving this knowledge-building agenda is the desire of government agencies to improve understanding of firm practices and performance and, in doing so, to foster better policy design and implementation.

What are the implications for the development of international innovation indicators? The work presented here advocates for a broad statistical interpretation of innovation activities and outcomes, to mitigate the risks of vesting our understanding of good business practices in a limited set of variables. Both activity and outcome indicators could take on a more composite nature, with a focus less on single high-level outcomes and more on the *bundles* of activities and competencies that are required to deliver superior firm performance. Such an approach would naturally lead to data collections that are more interdisciplinary in their theoretical grounding. At the same time, much more attention could be paid in statistical outputs to measuring the persistence of firms' innovation behaviours. Such a longitudinal approach, together with firm-level performance data, would increase the ability to quantify the impact of innovation on economic growth.

An ongoing sustained effort is required to inform our understanding of the innovation process. That effort is only partly about future indicator development. For example, in New Zealand there are four strands to current BOS-related research: the production of detailed economy-wide innovation statistics (SNZ 2007); micro-econometric research using panel data to examine the two-way causal relationship between practices and performance, particularly the way in which firms' practices change in response to market signals; detailed case study follow-up of 50 BOS respondents to gain a deeper understanding of New Zealand business practices; and participation

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in the National Experts on Science and Technology Indicators (NESTI) cross-country innovation project to draw internationally comparable research results from the dataset.

New Zealand is fortunate that the modular design of the BOS allows some scope (over time) to compensate for our limited ability to form a comprehensive picture of how firms behave. It is in the nature of surveys that judgements are needed to prioritize questions. Despite the best intentions, the models applied to these judgements will inevitably lead to the non-collection of data on important subject areas. The research program outlined above, together with the broad review of the New Zealand national innovation policy (OECD 2007a), is designed to deepen understanding of the innovation process and, in doing so, to test the global view reflected in the BOS.[24]

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24. In the same way that, for example, the international case study literature informed the design of organizational change and complementary investment questions in the ICT module of the BOS (Fabling 2005).

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Chapter 10

UNIVERSITY RESEARCH IN AN "INNOVATION SOCIETY"

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University of Calgary

10.1. Introduction

In monitoring and measuring the performance of national and regional innovation systems, the role of universities has become one of the most hotly contested issues. It is accepted that the university can be a source of new ideas that may eventually transfer to the market. However, there is much debate about how transfers actually occur and about their direct economic significance. Some use econometric arguments to show that academic research has a high return on investment (*e.g.* Mansfield 1991, 1998). Others argue that the "commercialization" of university research by entrepreneurial universities is an essential economic driver (Etkowicz 1983). But these views are countered with arguments that the greatest value of university-based research lies in the training of highly qualified personnel and the provision of basic scientific research and advisory capabilities (Nelson 1959, 1966; Cohen, Nelson and Walsh 2002; Feller 1989; Feller, Ailes and Roessner 2002).[1]

However, in the increasingly results-oriented research funding climate in most Organisation for Economic Co-operation and Development (OECD) countries, universities are being called upon more frequently to justify public investment by demonstrating that more new ideas are finding their way into commercial applications more quickly. The result has been an explosion of Technology Transfer Offices (TTOs), a new priority to create spinoff companies and increasing government interest in higher education R&D (HERD) figures. Accordingly, many universities have themselves

1. In most cases, even strong proponents of the university's role in research and development (R&D) concede this point. Mansfield (1991), for example, does not disagree that this is a key university function.

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come to see knowledge transfer as a means of leverage to obtain increased government funding.[2]

It has always proven difficult to demonstrate the overall economic impact of publicly funded, university-based research (Salter and Martin 2001). Moreover, most of the empirical evidence that has been produced to date tends either to question assumptions about the extent or significance of commercialization and spinoffs, or to suggest that the relationship is fragmentary, inconsistent and highly context-dependent (Mowery *et al.* 2001; Nelson, Peterhansel and Sampat 2001; Cohen, Nelson and Walsh 2002; Sampat, Mowery and Ziedonis 2003).

This chapter suggests that there is an even more challenging problem. The conventional statistical definition of university-industry knowledge transfer (*i.e.* what is and is not counted) is tied to a very narrow conceptualization of innovation as a phenomenon – one that is oriented almost entirely towards the production and application of new technology. As a consequence, evidence for the performance of university-industry knowledge transfers is gleaned more or less exclusively from indicators associated with the inputs and outputs of science and engineering (S&E) laboratories. The contention in this chapter is that the indicator regime so oriented misrepresents and very probably underestimates the role and value of university research in the innovation process.

The discussion begins with a reconceptualization of the dynamics of innovation in terms other than the production of technology. Instead, these dynamics are explored in the context of an "innovation society" – a heuristic device for visualizing innovation not just in terms of individual new inputs (be they technologies, methods, organizational forms, etc.), but also in terms of the assimilation and absorption of factors like these by various social groupings, such that the result is observable change in behaviour or practice. In other words, the proposal is to define and assess innovation in terms of changes in the socio-economic fabric, rather than in terms of any specific contributing factor, technological or otherwise.

Inevitably, this leads away from production-oriented perspectives and forces a confrontation with the problem of how demand for innovation is expressed and fulfilled. Specifically in the university-industry knowledge transfer context, it is proposed here that the need to understand demand factors broadens the kinds of knowledge that industries require in order to be

2. For example, the Association of Universities and Colleges of Canada (AUCC) has proposed a "deal" by which government contributions to overheads would increase in return for a doubling of university-based R&D and a tripling of commercialization revenues by 2010 (AUCC 2005).

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able to respond to the complexity of the socio-economic environments in which they seek to place new goods and services.

Within this framework, technology becomes just one of many knowledge streams that must come together in order for innovation to occur. Without the assumption that technology is the primary and causal factor in innovation, there is far more scope for understanding the role of technology in a more nuanced way, particularly as an interdependent, or even dependent, factor in innovation. From this standpoint, the scope of university-generated knowledge that could be relevant in any innovation context is broadened considerably.

Having adopted the “innovation society” perspective, the chapter goes on to construct a critique of the current indicator regime for assessing the university’s contribution to the innovation system. The university occupies a unique and pivotal position in the “innovation society.” Universities do produce and sometimes directly exploit knowledge, but increasingly many other institutions both collaborate and compete with universities in this endeavour (Hicks 1995). But no other institution links the production of knowledge to the development, application and dissemination of knowledge production skills and capabilities. This significantly widens the number of potential knowledge transfer pathways, very few of which are represented in the current indicator regime.

Many of these potential pathways do not emanate from basic or applied science laboratories. Instead, they may come from a diverse array of social, life and management sciences and, in some cases, also from the arts and humanities. Their role is to enhance the ability to understand and influence the socio-economic milieu in which innovation occurs. Building on previous work that suggests how these inputs can be assessed more systematically in an innovation context, this chapter shows that the “innovation society” contains a variety of roles for many different kinds of knowledge, and that no particular form is necessarily dominant. It is proposed that, to understand the innovation process in more of its complexity, there is a need to begin valorizing and measuring more types of knowledge inputs.

Finally, with brief reference to case studies and examples, the chapter demonstrates how indicators could be developed that reflect more adequately the nature and extent of university interaction in the innovation process. The extent and significance of this interaction is probably much greater, more direct and more diverse than demonstrated in the current indicator regime.

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10.2. The "innovation society": defining the socio-economic context for university knowledge transfer

Most scholars have discredited simplistic models in which innovations are seen to flow directly from the transfer of basic scientific knowledge to industry. Current models stress the interactivity and reflexivity between basic and applied science and between technology and markets. Nevertheless, there remains a heavy emphasis on investigating innovation in the virtually exclusive context of technology. Indeed, post–Nelson and Winter (1977, 1982), the focus has been predominantly on the dynamics of technology production and adoption in firms.

Freeman (1994) suggests that the reasons for the historical emphasis on technical change have been methodological: a need to reduce the complex social parameters of innovation to a more manageable set of variables for economic modeling. He is certainly correct. As economics is fundamentally a production-oriented science, technology is attractive as a surrogate for innovation because it is a measurable industrial output. It is not surprising, therefore, that for indicator purposes "innovation" has been conceptualized almost exclusively as "*technological* innovation," irrespective of the nature or extent of the role actually played by technology in this process.

Thus, most of the indicators in current use (particularly patents, R&D data and publications data) are oriented, in effect, towards invention.[3] This, despite admonitions in virtually all the significant innovation literature since Schumpeter that invention and innovation are different (even if related) and that, in many cases, the analytical parameters of innovation may not be related to technology at all. Crucially for a more holistic "societal" conceptualization of innovation, virtually none of the indicators in current use gives any adequate explanation for what motivates the innovation process in the first place.

Exploration of the issue of motivation, which would bring a broader range of social factors into the innovation context, has largely been either sidelined altogether or confined to interpretive case studies. However, stimulated most recently by an intensified interest in service innovation, social scientists have begun to take the idea of a social calculus of innovation more seriously, dispelling the notion that innovation can or should be explained mainly in terms of conventional manufacturing-oriented factor

3. It is, however, noteworthy that for many years invention has not been the main orientation of national or regional innovation surveys covering many OECD countries, or indeed of the *Oslo Manual* (OECD/Eurostat 2005). Since the early 1990s, the official statistical definition of innovation has evolved considerably to encompass processes and services (see Earl and Gault 2006).

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inputs (Lancaster 1966; Cornwall 1977; Miles *et al*. 2000; Setterfield 2002; McMeekin *et al*. 2002; Tidd and Hull 2003; Cowan, Cowan and Swann 2004).

For producers, the motivation to innovate may be simply to gain advantage over other producers. But this may not correspond to how end users or consumers formulate demand for products or services. For example, Lancaster (1966) suggests that consumers' buying decisions are made not on the basis of product utility, but according to consumer perceptions of the social functions of goods. In other words, people do not purchase automobiles; they purchase personal mobility along with social status (see also Swann 2001).

In an "innovation society" framework, the motivation for innovation would not be expressed simply as demand for goods, but rather as demand for change in how individuals or social groupings live in the world – that is, in *how* as well as *what* they produce and consume.

This proposition points back to Schumpeter's definition of innovation, which was simply "doing things differently in economic life" (Schumpeter 1939) – a definition entirely consistent with his lifelong view that, although innovation may include technological change, there is no necessary or exclusive relationship between innovation and (particularly "new") technology. To innovate, it is enough to deploy existing technology in new contexts, or simply to market goods and services in new ways (Schumpeter 1912, 1950). Indeed, Schumpeterian innovation revolves mostly around the entrepreneurial function of anticipating, creating and organizing markets, whether the goods and services involved are technological or non-technological, existing or new.

In this regard, most scholars of innovation have noted the requirement for complementary actions and assets, particularly with respect to the need to coordinate technology with the environments in which it will be implemented (Nelson and Winter 1982; von Hippel 1988; Cowan, Cowan and Swann 1997; Roehrich 2004). However, technology is almost always identified as the primary driver of this coordination process, or as the central input around which the innovation process as a whole revolves.

But, in truth, the question of which inputs constitute the cart and which the horse is entirely open. For example, new value-producing configurations, business models or financial instruments can be the definitive factors in establishing the commercial viability of a new technology – that is, making it possible for the technology to become part of an innovation (Stabell and Fjeldstad 1998; Afuah and Tucci 2001; Chesbrough and Rosenbloom 2002; Chesbrough 2003; Hawkins 2003; Tassey 2004). Thus, for example, Mandel (2000) argues that the technological developments in Silicon Valley during

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the 1990s would have been impossible but for innovations in the regulatory environment and financial instruments that permitted unprecedented degrees of access to venture capital. For him, the so-called "new economy" is more about access to investment capital than to computer technologies and the Internet.

10.3. The problem of indicators for university-industry knowledge transfer

Studies using the current indicator regimes have yielded a vast amount of knowledge about innovation in the specific context of the production of goods (less so for services). But when this knowledge is applied to assessments of the broader social dimensions of innovation and particularly the role of public institutions – in this case, universities – some fundamental questions about the entire indicator regime are thrown into sharp relief.

Figure 10.1 illustrates a hypothetical "sequence" for the innovation process that employs commonly used descriptive categories, but in a configuration that is more consistent with the "innovation society" framework as just outlined. It should be noted that, although the process depicted in Figure 10.1 is referred to as a sequence, feedbacks are likely at various stages, and the process can be diverted, halted, abandoned or restarted accordingly.

It is assumed that innovations are instigated by multiple and not necessarily coordinated demand factors or *motivations*. Each of these can yield various *actions*, which typically involve making *inputs* of time, money, knowledge, materials, human resources and so forth into various *processes*, such as research, development, production or distribution. The result of each action is an *output* or *outputs*, which can emerge in the abstract form of new knowledge (whether codified or tacit) or in a more concrete form as an invention. Outputs can remain outputs – *i.e.* they are never exploited – or they can yield *outcomes* in the form of various applied endeavours and enterprises. The result of such outcomes can be *innovation*, which has been defined specifically in the "innovation society" context as an observable change in the patterns, behaviours and practices of human life. Thus, in this framework, *impacts* are distinguished from outcomes. It is proposed that impacts are the ultimate evidence that innovation has occurred and that in some way they will influence motivations for stimulating further innovation activities. The presumption is also that impacts may become evident only after the passage of considerable time.

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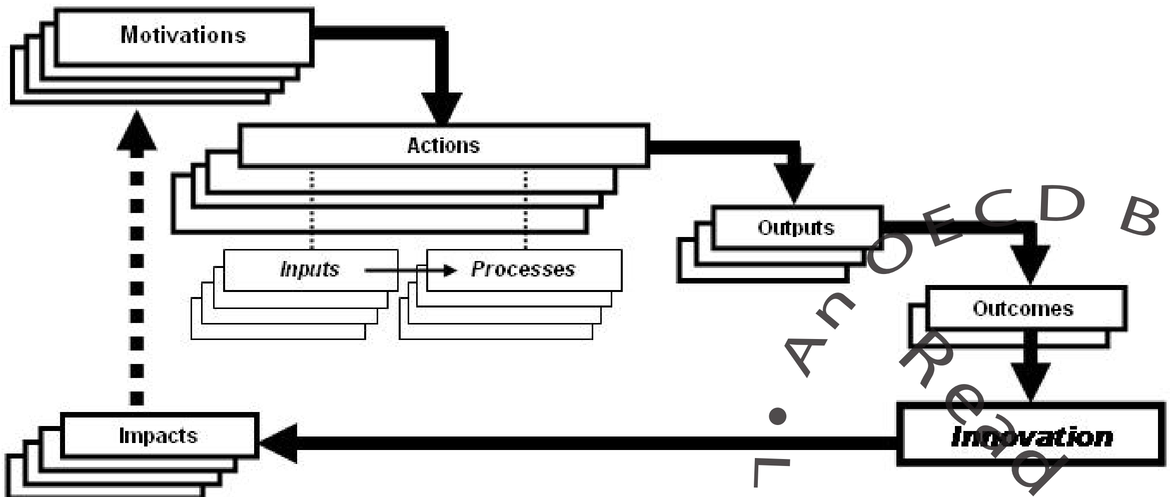
Figure 10.1. The “innovation society”



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Comparing Figure 10.1 to the current base of innovation indicators, it is clear that the focus of the latter is almost entirely on inputs and outputs. Outcomes and impacts do figure in the indicator regime, but often these categories are confused with one another or are conflated, thus leaving a huge analytical gap between the immediate, concrete consequences of outputs and the longer-term additional effects of innovations on a broader range of socio-economic phenomena.

A sharper distinction is preferable. Thus, if a patent is an output, then an exercised licence in a spinoff firm is an outcome. Similarly, a published research report is an output, and its use as the basis of a new standard method of analysis is an outcome. Economic impacts would include demonstrable changes in standard macroeconomic indicators. Non-economic impacts would include fundamental changes in perception or practice: for example, the reconceptualization of the place of humans in the world that is associated with the Darwinian revolution.

Inputs, outputs, outcomes and impacts constitute only one indicator axis – namely, what is measured. The other axis concerns the relationship of the data to the phenomena being measured. On this axis, indicators can be distinguished as measurements, surrogates or correlates (Jaffe 1998). Measurements are the direct quantification of phenomena: for example, counts of firms with origins in the university measure the extent of spinoff firm formation. Surrogates are indirect representations of phenomena linked by explicit hypotheses: for instance, the expenditure of research dollars indicates research effort. Correlates are quantities linked to a phenomenon by a statistical hypothesis: for example, the level of employment of highly qualified personnel may be a correlate of innovation activity.

Distinguishing between actual measurements and surrogates or correlates is critical to understanding the policy implications of indicators. Table 10.1 uses the two indicator axes to present indicators that are currently associated most prominently with university research.

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Table 10.1 Classification of indicators associated with university research, with examples

(Modified from Jaffe 1998)

	Measurements	Surrogates	Correlates
Inputs	Effort (person or equipment years)	Expenditures (*e.g.* HERD)	
Outputs	Discoveries Inventions Human capital	Papers Citations Expert evaluations Patents[a] Degrees	Prizes Patents[a] Higher-education expenditures
Outcomes	New devices New drugs	Patents New drug applications	Licences
Impacts	Economic growth	Gross domestic product (GDP)	Gross domestic expenditure on R&D (GERD), business expenditure on R&D (BERD), HERD
	Productivity growth Environmental improvement Public appreciation	Productivity metrics	Emission levels Science in newspapers

10.4. Towards a new model of university-industry knowledge transfer

At present, inputs into university laboratories are measured almost exclusively in terms of levels of public and private investment in basic research. In Canada, for example, HERD is dominated by the amount of public research funding allocated to the natural and applied sciences. Increasingly, outputs are also monitored, but almost entirely in terms of production-oriented indicators (patents, publications or prototypes). Furthermore, the end point of university involvement in the innovation process tends to be defined in terms of the commercialization of specific laboratory outputs (which may represent only a tiny fraction of total laboratory output), often as it relates to the creation of spinoff companies. But even here, only the quantity of spinoffs and commercial applications is measured.

The contention here is that these indicators not only fail to encompass an appropriate range of knowledge that is already known to be transferred from the university to the innovation process, but also, by focusing too narrowly

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on the natural sciences and engineering, create an artificial barrier to understanding the actual scope and significance of this process.

Landry, Amara and Lamari (2001) show that university research outputs in selected areas of social science also transfer to the marketplace, and that, as far as the actual transmission of knowledge is concerned, they often appear to do so somewhat more efficiently than natural science and engineering outputs.[1] Moreover, Hearn, Cunningham and Ordonez (2004) demonstrate how, in today's service-rich economy, university research outputs in fine and applied arts can be transferred to the market as high-value commercial products and services as surely as and in similar ways to outputs from engineering laboratories.[2] Furthermore, Audretsch, Lehmann and Warning (2004) indicate not only that university-industry transfers emanate from a broad range of disciplines, but also that different knowledge transfer dynamics can be observed for different knowledge sources within the university – transfers from social science being more likely to require physical proximity to specific industry sites than transfers from natural sciences and engineering.

10.4.1. Exploring knowledge pathways

The key to understanding the dynamics of these other modalities of knowledge transfer is to focus on the variety of possible outcomes from university research. The complexity of these outcomes has been recognized widely in research policy documentation (*e.g.* Martin and Salter 1996; Reamer, Icerman and Youtie 2003; Lambert 2003; Molas-Gallart *et al*. 2002; AUCC 2005; Munn-Venn 2006). These reports and reviews identify many diverse pathways along which outcomes emerge from university research.

For the purposes of this discussion, the seven-part categorization of research "benefits" adopted by Salter *et al*. (2000) is suitably representative as a guide to the various pathways that knowledge produced in universities may follow on its way to becoming an applied outcome:

1. Landry, Amara and Lamari (2001) focus on six social science fields, two of which (social work and industrial relations) are oriented towards practical application. Political science and economics represent commonly required skills in administrative, policy and managerial contexts. Sociology and anthropology are core sciences in management and market research.

2. Indeed, the size of "cultural" goods markets can be enormous. For example, in the United States in 2002 (the last year of available business census data), the US motion picture industry had total receipts that were substantially larger than those of the US computer hardware industry.

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- Forming networks and stimulating interaction;
- Creating new firms and licensing patents;
- Creating new scientific instruments and methodologies;
- Increasing capacity for scientific and technical problem solving;
- Increasing the stock of useful knowledge;
- Training skilled graduates;
- Creating "social knowledge" (*i.e.* knowledge about the socio-economic environment).

Within such a scheme, the problem becomes one of identifying a balanced set of indicators for all the pathways from which outcomes emerge, be they technological or not. Clearly, the attention that input and output indicators now receive is a consequence of the hypothesis (not always explicit) that they are correlates of the growth of knowledge stocks, the training of research graduates and an increasing capacity for problem solving. In this section, it is argued that indicator development should be aimed at understanding both the mechanisms associated with the above pathways and the ways in which specific knowledge streams follow these pathways into the innovation process.

An easily implemented first stage in characterizing this wide variety of possible knowledge transfer pathways would be to propose indicators of targeted additions to existing qualitative and quantitative research that investigate phenomena related to these pathways. Several studies have already begun to address the indicator problem from this perspective (*e.g.* Molas-Gallart, Tang and Morrow 2000; Molas-Gallart *et al*. 2002).

To illustrate some of these dynamics further, the authors of this chapter offer some preliminary observations based on their own analysis of data relating to knowledge transfer patterns within the University of Calgary. Detailed relevant information was drawn from three sources. First, the university permitted a statistical analysis of faculty annual reports filed in 2004 that dealt comprehensively with three areas of responsibility: teaching, research and service (administrative and planning activities involving faculty members, as well as community contributions); these reports covered 100% of over 1 300 continuing full-time staff. Second, 219 faculty members responded to a survey questionnaire administered by the authors. Third, a number of respondents agreed to be interviewed about their individual knowledge transfer experience.

Analysis of the faculty annual reports revealed 81 instances of activities identified as conventional "technology transfer." The leading faculties were:

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Engineering	35 transfers	0.28 per faculty member
Medicine	14 transfers	0.03 per faculty member
Environmental design[3]	7 transfers	0.28 per faculty member

Activity related to intellectual property (IP) was substantial, but was centred in only a few faculties. A total of 101 reports of patents, copyrights and registered industrial designs were filed in 2004. The leading performers were:

Medicine	37 reports	0.09 per faculty member
Engineering	33 reports	0.28 per faculty member
Science	30 reports	0.14 per faculty member

Otherwise, most of the knowledge flows had no exclusive orientation towards technology. The most significant observation arising from the faculty annual reports was the relatively wide distribution across faculties of consultancy and community service activities. Even though one might assume that consulting is an under-reported activity among university faculty, there were over 500 reported instances of consulting to firms (the majority), governments and organizations. Medicine reported 220 such assignments, engineering 73 and environmental design 67. If reckoned in terms of consultancies per faculty member, however, the highest concentration occurred in environmental design, which is much smaller than the medicine and engineering faculties:

Environmental design	2.68 per faculty member
Kinesiology	0.81 per faculty member
Engineering	0.57 per faculty member

The faculty survey asked respondents what they perceived to be the best way to achieve social benefit from research. The results were as follows (individuals could choose more than one response):

Publication in the open literature	144
Collaboration with knowledge users	100
Launching a venture or business	19

Although few respondents rated launching a venture or business very highly, 39 respondents indicated that they had actually started a business or other venture that created employment and/or revenue, and another 15

3. This faculty includes architecture, industrial design, environmental sciences and planning.

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expressed an intention to do so. Significantly in this category, the leading faculties included social science, as well as medicine, engineering and science. Once again, the most common form of active knowledge transfer was through direct contact with knowledge users.

The survey also probed the outcomes of consulting and collaborative activity. The benefits to partners were identified most frequently as occurring in the following forms:

Market entry or expansion	26%
New products or services	23%
Improvement to a product or service	22%
Administrative systems, new or improved	15%

The semi-structured interviews offered further insights into the variety of processes involved and highlighted the limitations imposed by the complexity of the knowledge transfer relationship on the significance of the statistical summaries of the annual reports and the survey. Table 10.2 presents several examples from these interviews of actual knowledge flows that correspond to each of the pathways identified by Salter *et al*. (2000).

Table 10.2. Qualitative identification of knowledge pathways

Knowledge pathway*	Type of example identified in interviews
Forming networks and stimulating interaction	• Major research consortia • Direct participation in a large-scale industry project
Creating new firms and licensing patents	• Successful licensing to an established firm • Spinoff involving a university scientist
Creating new scientific instruments and methodologies	• Services from a unique university research facility • Development of a new diagnostic protocol
Increasing capacity for scientific and technical problem solving Increasing the stock of useful knowledge	• Consulting o Contributing to the development of effective project management practices o Working in a regional R&D cluster
Training skilled graduates	• Hiring graduates • Recruiting research associates internationally who remain in a local cluster
Creating "social knowledge"	• Social factors in project contract construction

*Knowledge pathways identified by Salter *et al*. (2000).

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It is fascinating to evaluate these preliminary findings with the "ladder of knowledge utilization" concept introduced by Landry, Amara and Lamari (2001). As shown in Table 10.3, this provides a process view that relates knowledge use to decision-making processes using a scale with six cumulative stages of knowledge utilization in ascending order.

Table 10.3. Stages of the ladder of knowledge utilization

(Adapted from Landry, Amara and Lamari 2001)

Stage 1: Transmission	User obtains knowledge
Stage 2: Cognition	User absorbs knowledge
Stage 3: Reference	User cites and elaborates knowledge
Stage 4: Effort	User deploys knowledge
Stage 5: Influence	Knowledge is used in decision-making
Stage 6: Application	Knowledge is applied directly to products, services, processes, etc.

Landry and his colleagues apply this model to empirical analyses of large samples of Canadian social scientists, natural scientists and engineers, and their overall observations are highly relevant to indicator construction. As the complexity of the relationship between university researchers and industry increases, so usually does the rate at which the knowledge ladder is ascended. Basic research projects tend to have relevance mainly near the bottom of the ladder, whereas more collaborative and applied projects tend to be found towards the top.

10.4.2. Some possible next steps

A report on measuring the socio-economic impacts of academic research in the United Kingdom (Molas-Gallart *et al.* 2002) offers a large number of possible metrics, with warnings about difficulties, costs and needs for further research. It is notable, however, that a majority of studies still focus on the single pathway of spinoffs and licensing. Nevertheless, even using already accessible data and more or less standard methods, it would be possible to take several immediate steps to improve indicators in the other six outcome categories.

10.4.2.1. Step 1: Normalize cost input indicators

Financial input data (*e.g.* HERD) are widely available and used frequently. These data are also widely interpreted as a correlate of *all* the outcomes. But their analysis should be balanced to recognize the fact that different types of knowledge have different production costs. For example,

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input data indicate generally that the costs of medical research exceed those of S&E research, which in turn exceed the costs in all other fields. Input data should be normalized for the scale of research expenditure in each of the contributing disciplines and knowledge streams.

10.4.2.2. Step 2: Match graduate knowledge indicators with innovation roles

There is reasonable consensus that knowledge transfer by graduates is the most significant pathway for the influence of university research (Salter *et al*. 2000; Munn-Venn 2006). But this poses a challenge for indicator development. A tantalizing hint of what is possible can be detected in the Canadian National Graduate Survey (Statistics Canada 2002), which has analogues in many countries. Currently, the survey provides information about the educational requirements for various jobs. But it does not link job descriptions, educational requirements and knowledge fields with a model of the innovation process. At a more concrete numerical level, there is considerable information on relative wage patterns among young, highly educated workers based on census data (see, for example, Morissette, Ostrovsky and Picot 2005). On the basis of the hypothesis that wage patterns in knowledge-intensive sectors are correlated to creative contributions, wage data could be examined in terms of possible knowledge stream decompositions that could track the contribution to innovation of employees with different qualifications.

10.4.2.3. Step 3: Valorize new instruments and methodologies

The development of new instrumentation and methodologies is a key output of university research (Rosenberg 1992), and close parallels have been noted between the instruments and methodologies developed in basic research and those adopted by firms (von Hippel 1988). Salter *et al*. (2000) suggest that this is the second most important contribution (after human resources) of university research to economic activity. There has been considerable interest in indicators derived from firms' investments in capital equipment, but the origins of this equipment in university research could also be tracked.

10.4.2.4. Step 4: Build partnership indicators

It has been a mistake to group all industry funding and all government funding into separate silos. The observations from the analysis of the University of Calgary data suggest that all the knowledge pathways are supported by active interaction with users. If the Landry model is applied to funding sources, then research funding associated with user sponsorship and participation is likely to correlate to outcomes. Key examples of this type of

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funding are research consortia that include users, industry-sponsored research chairs, and research contract work in laboratories that have continuing contract research relationships with users. It would probably not be difficult to segregate data on these types of research sponsorship. Thus, an input measure is proposed for funding modalities where industry and university researchers are involved in longer-term relationships. In this case, industry funding should be summed with the relevant granting agency contributions to provide an overall indicator of research funding for partnership activity.

10.4.2.5. Step 5: Expand university faculty surveys

In universities that use annual reporting systems, statistical summaries of activities in various categories can provide insight into levels of activity at different stages of the knowledge utilization ladder. An effort should be made to define standardized reporting categories so that these outcomes can be clarified. If annual reports cannot be widely accessed, a new national survey project could present the questions to a sample of university faculty. Such a survey would be a valuable complement to existing firm-level innovation surveys, and at least two significant new outcome indicators could result:

- Participation in user seminars and conferences as a surrogate for increasing problem-solving capacity and network building; and
- Publication and presentation in user-oriented media, including trade journals and general media, as a correlate for increasing the stock of useful knowledge at the third stage of the knowledge utilization ladder or higher.

A faculty survey instrument might deliver many kinds of additional information. Analysis of currently available annual report data makes it clear that a better understanding of faculty IP activity is possible than that derived from the reports of TTOs, and that a more nuanced understanding of consulting activity might also be achieved. Since IP activity that is not reported through TTOs frequently reflects projects done in partnership with users, it might be a significant indicator of more diverse and complex relationships. A clearer understanding of consulting activity might allow differentiation of the role played by this important but under-documented activity in several of the knowledge flow pathways.

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10.4.2.6. Step 6: Develop social knowledge indicators

The fundamental hypothesis motivating this chapter is that innovation must be perceived as a holistic social process involving the combination of many more knowledge dimensions than are normally covered by technology. University research and training encompass the full range of human knowledge. Thus, much university research is oriented towards the social knowledge pathway. Appropriate indicators would need to come from revised innovation surveys that are relevant to a broader range of industries. Employment surveys would have to probe the changing roles of highly qualified personnel.

10.5. Conclusion

The concept of an "innovation society" was developed as a heuristic device to revitalize the original emphasis of Schumpeter and others on the systemic societal dynamics of innovation. In the context of indicator development, it is a way of arguing for a broader definition and more nuanced calculus of knowledge production and transfer in the innovation process.

This chapter has shown that the basis for expanding this calculus already exists, and that many elements could be implemented relatively quickly provided that innovation is conceptually reframed as stemming from the outcomes of various forms of knowledge application and not just from financial and technological inputs and outputs relating to industrial firms. Instead, the broader societal dimensions of knowledge production, transfer, application and evaluation must be considered, and particularly the role of knowledge as produced in disciplines other than the natural and applied sciences. The university occupies a crucial position in this structure, and researchers must learn to characterize more of its knowledge outputs statistically if they are to assess its true role in the innovation process.

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Chapter 11

THE INTERNATIONAL MOBILITY OF DOCTORATE HOLDERS: FIRST RESULTS AND METHODOLOGICAL ADVANCES

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11.1. Introduction

Research activity has often involved intense exchanges among those in charge of conducting the research, and these exchanges have always ignored national barriers. As early as the Middle Ages, the elite from all over Europe and elsewhere travelled the world to learn from their counterparts abroad. However, historical and political events, such as the Second World War, have driven and sometimes changed the intensity and direction of these movements. Many scientists have left Europe to find better working conditions on the other side of the Atlantic, prompting a debate on the so-called brain drain. Nowadays, the globalization of the economy and its knowledge base has increased the demand for the highly skilled and has become the main driver of the international mobility of researchers (Basri 2007). For this reason, international mobility is becoming more prominent on the policy agenda of those in charge of monitoring science, technology and innovation (STI). Many policies, at both the national and institutional levels, are implemented to encourage mobility while at the same time attracting and retaining talented people. The question remains, however, as to what the optimal level of mobility is and what balance should be sought between incoming and outgoing researchers. While the possible brain drain from developing countries is much debated, as well as the large flows of the highly skilled to the United States, the US National Science Board (NSB) has expressed concern about the small number of US scientists and engineers going abroad for study or research and has made recommendations to remedy this situation (NSB 2001, 2003).

Yet, assessing the flows of the highly skilled, measuring their international mobility and differentiating between migration and temporary mobility prove to be real challenges for statisticians. Migration indicators have tentatively compensated for the apparent inexistence of international mobility indicators, but the inherent weakness of international migration

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statistics and the fact that these statistics rarely take into account the level of qualifications of the people covered by them have compounded the problem. The Organisation for Economic Co-operation and Development (OECD) has been working for several years on issues relating to the international mobility of students, researchers, scientists and other highly skilled groups, while attempting to improve the available statistical tools (OECD 2001a). Of the various initiatives reviewed below, this chapter looks in greater detail at the project designed to follow the career paths of doctorate holders, the first results from which seem quite promising in terms of improving understanding of the cross-border movements of doctorate holders.

This chapter first offers some basic information about the current international statistical landscape, which is more or less confined to migration-type data. Yet, while migrations are by nature international, their measurement relies strongly on national concepts that are linked to countries' migration policies and to their policies for the acquisition of citizenship. This produces the following paradox: there is very little in the way of internationally comparable statistics on migrations. Moreover, education systems and qualifications differ greatly from one country to the next, and this influences the nature of the statistics describing them.

The chapter goes on to consider which databases recently introduced or enhanced within the OECD can be used to obtain data on the international mobility of the highly skilled. It then presents and discusses the initial results from a project launched in 2004 by the OECD, in co-operation with Eurostat and the United Nations Educational, Scientific and Cultural Organization (UNESCO), to measure the careers and international mobility of doctorate holders (the CDH project). These results shed some interesting light on the characteristics of the populations concerned in seven countries (Argentina, Australia, Canada, Germany, Portugal, Switzerland and the United States), and on possible new approaches that might improve the measurement of international mobility and migrations.

11.2. Statistics on international migrations

OECD countries have many different kinds of migration policies and systems. In schematic terms, a distinction can be made between the "immigration countries" that have been populated through successive waves of immigration (Australia, Canada, the United States and New Zealand), which use a system based on the granting of permanent residence permits, and other countries, for the most part in Europe, which tend to use a system of delivering temporary residence permits. This influences the sources of data used for measuring migrations at the national level, and also affects the definition of the immigrant population and the way it is counted.

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11.2.1. Data sources on international migrations

Four kinds of data sources on international migrations can be identified (for further details, see OECD 2001b, 269–75 and Lemaître 2005).

- Population or foreigner registers are used in many Northern European countries (Germany, Belgium, the Netherlands, the Nordic countries). Nationals and/or foreigners are supposed to register with the authorities, and this makes it possible to estimate the numbers of residents and immigrants. However, departures are not recorded as systematically as arrivals, and rules governing registration, and in particular length of stay, vary among countries. This affects the international comparability of the data from these registers.

- Residence and work permits are widely used in several OECD countries, including those that have population registers. The main difficulty in using them as a source of internationally comparable statistics is that the length-of-stay rule varies. The permanent residence permits granted by the "immigration countries" are of unlimited duration, while the temporary residence or work permits delivered by other countries are of variable duration depending on the country. Thus, the statistical coverage of certain migrant groups, such as students, varies from one country to another. Furthermore, the population groups targeted by such permits depend on the free circulation agreements in effect (the Schengen Agreement, for example). Nevertheless, efforts are underway at the OECD to establish harmonized flow statistics on arrivals, using visitor permits (OECD 2006).

- Population censuses and labor force surveys provide data not only on the foreign population, but also on level of education and occupation, which is generally not the case with the other data sources. Moreover, these sources are harmonized internationally. Their limitations have to do with their infrequency (in the case of censuses) and with the sample size for certain categories (in the case of labor force surveys).

- Specific surveys, such as for passengers entering or leaving a territory, are conducted in some countries. The best known is the United Kingdom's International Passenger Survey, but Australia and New Zealand use similar surveys.

11.2.2. Definition and measurement of the immigrant population

Several conclusions can be drawn from the preceding discussion. First, data on arrivals or immigrants are more systematic than those on departures or emigrants (emigrant numbers are often estimated using data for immigrants in the host country). Second, population censuses and labor force surveys,

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which are the most reliable sources for international comparisons, provide data essentially in the form of stocks rather than flows (which are more usefully derived from permits or passenger surveys). Third, although there is an accepted international definition of “migrant,”[1] this is not really taken into account in national statistics, for obvious reasons of compatibility with countries’ migration systems. This, together with the difficulty of tracking changes in individuals’ successive situations, makes it particularly hard to draw distinctions between short-term or temporary migrations and long-term or permanent migrations, and to identify successive or back-and-forth movements across borders.

The definition of the immigrant population also depends on countries’ migration systems. In the “immigration countries,” the most widely used criterion for defining an immigrant is place of birth, while in most other countries, especially in Europe, it is citizenship. This reflects the fact that the process of acquiring citizenship has historically been more systematic and swift in the “immigration countries,” as a means of encouraging settlement. This has an impact on the statistics resulting from these two measurements of foreign populations, as can be seen in Table 11.1.

The data in Table 11.1 illustrate the fact that, in all countries, the foreign population constitutes a larger share of the total population when measured by country of birth than when measured by citizenship (other data show that this is true beyond the six countries presented here). This is because a portion of the foreign-born population will have acquired citizenship of the country of residence. Another, albeit much smaller, portion of that population, however, will always have had citizenship of the host country despite being born abroad. This is the case, for example, with communities of repatriates from Portugal’s former colonies. On the other hand, depending on legislation, individuals born of foreign parents in a given country may not be able to acquire citizenship of that country. The issue of the definition of the immigrant population is thoroughly discussed by Dumont and Lemaître (2005) in their analysis of census data.

1. A long-term migrant is “a person who moves to a country other than that of his or her usual residence for a period of at least a year (12 months), so that the country of destination effectively becomes his or her new country of usual residence.” A short-term migrant is “a person who moves to a country other than that of his or her usual residence for a period of at least three months but less than a year (12 months), except in cases where the movement to that country is for purposes of recreation, holiday, visits to friends or relatives, business, medical treatment or religious pilgrimage” (UN 1998, 112).

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Table 11.1. Doctorate holders in six OECD countries, by origin (percentages)

	Australia (2001)	Canada (2001)	Germany (2004)	Switzerland (2004)	Portugal*	United States (2003)
Total	100.0	100.0	100.0	100.0	100.0	100.0
Citizens of the country	86.0	82.0	92.6	69.9	96.2	88.3
Foreign citizens	14.0	18.0	7.4	30.1	3.8	11.7
Total	100.0	100.0	100.0	100.0	100.0	100.0
Born in the country	53.6	45.9	82.5	58.9	84.6	74.3
Foreign born	46.4	54.1	12.0	41.1	15.4	25.7
Birthplace unknown			5.5			

*Data for Portugal are provisional and refer to doctorate holders who received their doctorate between 2000 and 2004.

Source: First OECD/Eurostat/UIS data collection on the careers of doctorate holders (CDH).

The shortcomings of these measurements suggest that it would be useful to cross-tabulate data using several criteria (place of birth, place of residence, citizenship, citizenship at birth, length of stay, etc.) in order to refine the interpretation of, and thus record more accurately, the immigrant, foreign or mobile population. The remainder of this chapter attempts to demonstrate this.

11.3. Two databases for measuring the international mobility of the highly skilled

11.3.1. The OECD Education Database

For many years, the OECD, in co-operation with the European Commission (through its statistical office, Eurostat) and UNESCO (through its Institute for Statistics (UIS)), has been collecting statistics on member countries' education systems. The three international organizations jointly issue a questionnaire, addressed to the authorities (ministries or statistical offices) in each country responsible for compiling the statistics, and the data collection covers education spending, personnel and students at all levels of the education systems.

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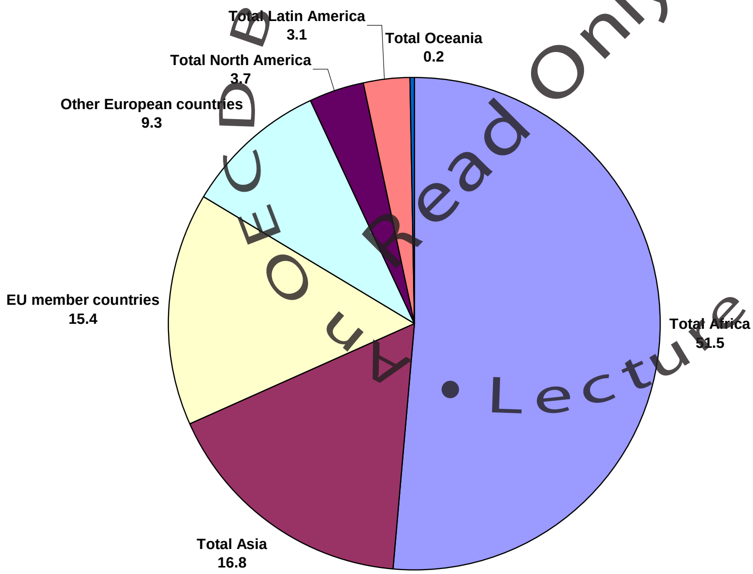
Figure 11.1a. Distribution of foreign students in France, by region of origin, 2003 (percentages)



Source: OECD Education Database.

One of the matrices produced by the OECD database was for many years that for foreign students enrolled in higher education in each OECD country, by citizenship, gender, level of diploma and field of study. The data were therefore collected in the host country (as illustrated in Figure 11.1a for France), but the combined host country–student citizenship tabulation also revealed students' choice of foreign destination through the distribution of students from one country of origin in their countries of study (Figure 11.1b).

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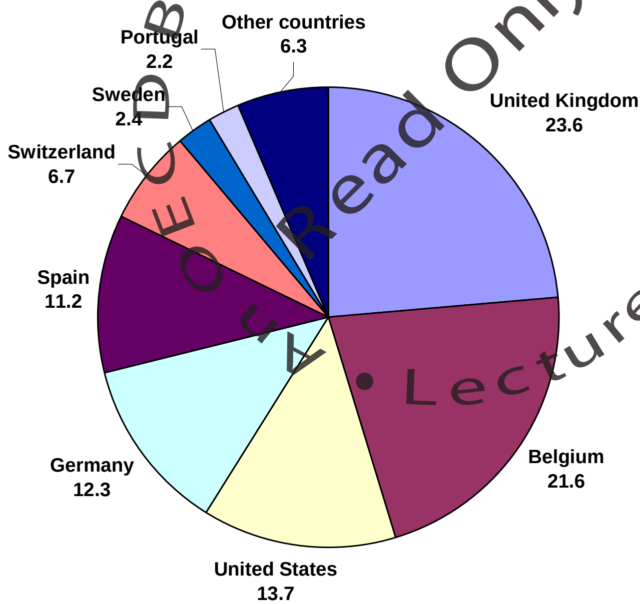
Figure 11.1b. Distribution of French students in other OECD countries, 2003 (percentages)



Source: OECD Education Database.

One of the problems in interpreting these data had to do with an issue already raised here – namely, the fact that they are gathered according to the criterion of citizenship. Thus, the OECD publication *Education at a Glance* (OECD 2005, 263) gave the reader the following warning:

> Students are classified as foreign students if they are not citizens of the country in which the data are collected. While pragmatic and operational, this classification yields some inconsistencies as a result of differing national policies regarding the naturalization of immigrants and the inability of several countries to report foreign students net of foreigners who are permanent residents in their country of study. Indeed, countries that naturalize immigrants stringently overestimate the size of their foreign student body, compared to more lenient countries. Bilateral comparisons of the data on foreign students should therefore be made with caution, since countries differ in the definition and coverage of their

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> foreign students. In particular, some countries only report foreigners who have come to their country expressly for the purpose of pursuing their education, while other countries report both resident and nonresident foreign students.

The group of national experts working on indicators of education systems (INES) considered this problem and proposed ways of improving the 2005 joint questionnaire. The approach selected was to gather data according to three variables in order to refine the information: citizenship, residential status in the country (temporary or permanent) and country of prior education. Results have been obtained for half of the countries, and they make it possible to determine, as a function of residential status or country of last diploma, whether there is student mobility. In countries of the European Union, it is the latter criterion that is the determining factor, because the notion of temporary or permanent residence loses its meaning with the application of the Schengen Agreement.

11.3.2. The OECD Database on Immigrants and Expatriates

Most OECD countries, and many other countries, held their last population census in or around the year 2000. The OECD took the occasion to gather the data from those censuses from national statistical offices and to establish a database on the number of residents in OECD countries, by place of birth, citizenship and level of education. The information contained in this database therefore reflects the cumulative effect over past decades of population movements within and towards the OECD zone. Moreover, it is possible to estimate the expatriate population from the number of residents in one OECD country born in another OECD country or in a non-member country, whether naturalized or not. Emigration rates have thus been calculated for about a hundred countries, and they include data on the highly skilled. These data show that most OECD countries are net beneficiaries of highly skilled migration (Figure 11.2).

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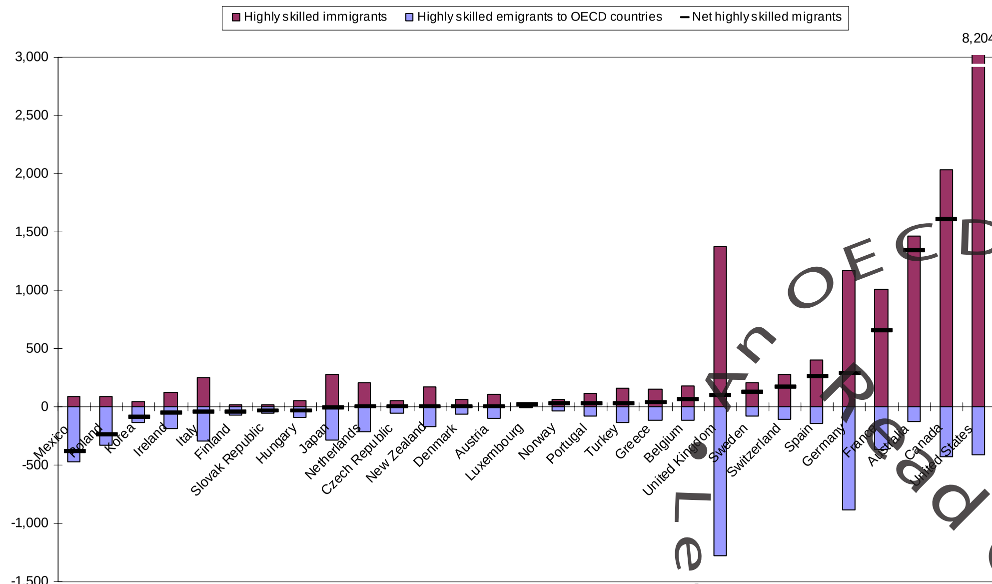
Figure 11.2. Immigrant and emigrant populations 15 years and over in OECD countries with a higher-education degree (thousands)



Note: Except for France (1999), the reference year for the data is 2000 or 2001, depending on each country's census year.

Source: OECD Database on Immigrants and Expatriates (version updated from Dumont and Lemaître 2005).

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It is expected that this database will be supplemented, in a second phase, with more detailed statistics by field of study, occupation, length of stay in a country and some other variables. The limitation on this exercise, however, lies in the fact that population censuses are infrequent and that the data quickly become obsolete. The exercise could nevertheless be repeated with the next census cycles.

11.4. Measuring the international mobility of doctorate holders: a new methodological approach

One of the missions of the OECD Directorate for Science, Technology and Industry is to follow trends in researchers' careers and in their international mobility. With this aim, it decided in 2004 to monitor a project to follow the career paths of doctorate holders, who constitute the pool of researchers, and to look closely at their international mobility. The effort to assess international mobility requires co-operation from the main countries of immigration and emigration, and partnership among various international organizations to coordinate the project. A group of experts was established, which currently represents 40 countries, including France, Germany, the United States, Canada, Australia, China, Russia and India, as well as some smaller countries, such as Uganda, that may experience a brain drain. The OECD, Eurostat and the UIS are jointly coordinating the project.

11.4.1. Interpretation of data on the origin and residential status of migrants

The methodology developed by the group of experts consisted of gathering data on immigrant populations through the host countries, while recognizing the difficulty of obtaining departure data and the need to avoid double counting. As well, the group decided to use several criteria relating to the origin of migrants, in order to interpret the migration data more accurately. Data on doctorate holders were therefore collected by country of birth and citizenship (whether by birth or by acquisition), cross-tabulated with residential status (permanent or temporary), length of stay in the country, previous country of residence, and other demographic or educational variables (in particular, country of previous degrees). The sources for these data could include population censuses, labor force surveys, targeted surveys (a methodology and a questionnaire for such surveys have been developed as part of the project), or a combination of these sources.

An initial data collection was conducted in September 2005, and some of the results are presented below. Seven countries (Argentina, Australia, Canada, Germany, Portugal, Switzerland and the United States) were able to provide data.

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Table 11.2. Citizenship of doctorate holders in four OECD countries, by type of citizenship (percentages)

	Australia (2001)			Canada (2001)			Portugal*			United States (2003)		
	Men	Women	Total	Men	Women	Total	Men	Women	Total	Men	Women	Total
Citizens of the country	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
by birth	61.0	63.5	61.7	53.5	64.7	56.6	87.5	87.3	87.4	82.7	87.0	84.2
by naturalization	38.1	35.4	37.3	46.5	35.3	43.4	12.5	12.7	12.6	17.3	13.0	15.8

*Data for Portugal are provisional and refer to doctorate holders who received their doctorate between 2000 and 2004.

Note: The numbers for Australia do not sum to 100 because of incomplete/missing data.

Source: First OECD/Eurostat/UIS data collection on CDH.

Table 11.3. Population makeup of a country, by origin of its inhabitants

	Citizens	Non-citizens
Native	1. Native and citizen by birth	5. Native and non-citizen
Native	2. Native and citizen by naturalization	5. Native and non-citizen
Foreign born	3. Foreign born and citizen by birth	6. Foreign born, non-citizen and permanent resident
Foreign born	4. Foreign born and citizen by naturalization	7. Foreign born, non-citizen and non-permanent resident

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As shown above in Table 11.1, these data confirm the differences in results obtained when the immigrant population was measured by country of birth and when it was measured by citizenship. The data on Australia and Canada show, in fact, that a considerable portion of their populations acquired citizenship of the country through naturalization (Table 11.2).

Data for Canada and the United States, not shown here, indicate that the populations born in each country were roughly equal to those holding citizenship of the country by birth, and that the foreign populations were roughly equal to those born abroad, minus the people who had acquired citizenship of the country (the difference being accounted for by nationals born abroad; see box 3 of Table 11.3). This is because birth within these territories automatically confers citizenship of the country; *i.e. jus soli* applies in their case: boxes 2 and 5 of Table 11.3 are equal to zero. This is not, however, the case in most other countries. In Germany and Switzerland, for example, legislation governing the granting of citizenship is much stricter, and children born to immigrant parents may not acquire the citizenship of their place of birth. Unfortunately, the data supplied by Germany and Switzerland in the course of this exercise were incomplete and could not be included here.

The fact remains, however, that for "immigration countries," such as Canada and the United States, the number of doctorate holders born abroad who had acquired citizenship (box 4 of Table 11.3) provides an indicator of definitive or long-term immigration, while the number of those born abroad who had foreign citizenship (boxes 6 and 7 of Table 11.3), with the exception of those who had chosen to retain their original citizenship even though they had settled definitively in the country, gives an indication of more recent immigration or of temporary mobility.

Information on residential status (permanent or temporary) can refine the data on the timing (recent or earlier) of arrivals in a country. The data on length of stay show that, among doctorate holders, a much higher percentage of foreign permanent residents in the United States had been in the country for 10 years or more than foreign non-permanent residents (Figure 11.3). The data on residential status reveal that the foreign-born population was much more integrated in Canada, either through naturalization or through the granting of permanent residence, while the foreign non-permanent resident population was more significant in the United States (Table 11.4).

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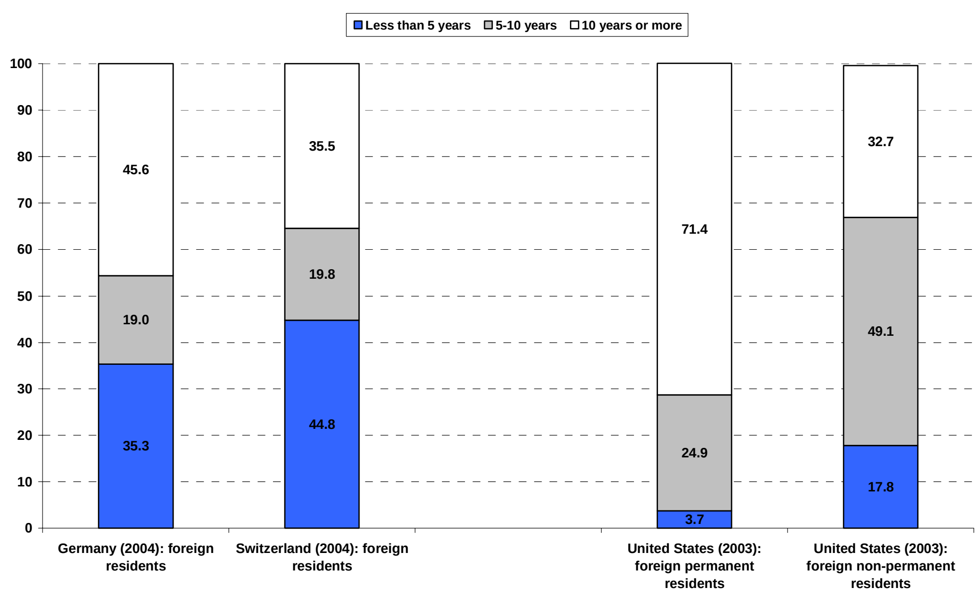
Criteria for granting nationality/citizenship in OECD countries

There are two rules that determine an individual's nationality/citizenship of origin: *jus soli* or "law of the soil" and *jus sanguinis* or "law of the blood," relating respectively to place of birth and to parents' nationality. While one will take precedence over the other depending on the country, it is common to find a combination of both. A distinction must be made, then, among three categories of countries: those where *jus soli* predominates and there is little recognition of *jus sanguinis*; those where *jus sanguinis* prevails; and those where both *jus soli* and *jus sanguinis* are applied. The classification of any country in one of these categories may, however, change over time as legislation evolves.

1. Countries where *jus soli* predominates: this is the case for Canada, Ireland and the United States.
2. Countries where *jus sanguinis* prevails: Austria, Denmark, Finland, France, Germany, Greece, Italy, Japan, Luxembourg, the Netherlands, Norway, Spain, Sweden, Switzerland and Turkey grant citizenship to a child if one of its parents has that citizenship.
3. Countries where both *jus soli* and *jus sanguinis* are considered in granting citizenship: a child born in Australia, Belgium, New Zealand, Portugal or the United Kingdom will have the citizenship of that country if, at the time of its birth, one of its parents held that citizenship or was permanently settled in the territory.

The acquisition of citizenship by naturalization is based on other criteria: age, residence, lack of criminal record, means of support, etc. (updated and adapted from OECD 1995, 165–89).

Figure 11.3. Length of stay of foreign resident doctorate holders in the host country (percentages)



Source: First OECD/Eurostat/UIS data collection on CDH.

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Table 11.4 Residential status of foreign-born doctorate holders in Canada, the United States and Portugal (percentages)

	Canada (2001)	United States (2003)	Portugal*
Citizens	**67.8**	**55.9**	**90.4**
By birth	0.9	3.6	78.6
By naturalization	66.9	52.4	11.7
Foreign citizens	**32.2**	**44.1**	**9.6**
Permanent residents	26.1	30.0	6.6
Non-permanent residents	6.1	14.1	1.7
Unknown			1.3
Total	**100.0**	**100.0**	**100.0**

*Data for Portugal are provisional and refer to doctorate holders who received their doctorate between 2000 and 2004.

Note: Columns may not sum to 100 because of rounding.

Source: First OECD/Eurostat/UIS data collection on CDH.

Table 11.4 also shows very clearly a feature peculiar to Portugal: the importance of the foreign-born population holding citizenship by birth, which accounted for 78.6% of the entire population born outside the territory. These were individuals who were repatriated at the end of the colonial wars, following Portugal’s decolonization process.

Finally, supplementary data on date and place of doctorate awarded and previous degrees attained, as well as on length of stay in the country, can be used to qualify the type of migration/mobility involved. Similarly, this information, supplemented by other data on intention to remain in or leave the country, can be used, in the case of recent immigration or of countries where naturalization rates are low, to clarify the figures on doctorate holders with foreign citizenship.

11.4.2. Use of supplementary variables to measure mobility

More data on date and place of doctorate and previous university degrees, as well as information on intention to stay in or move out of a country, have been collected and are presented here.

Table 11.5 shows different patterns across countries for where doctoral degrees were received. First, the percentage of citizens of the three reporting countries who received their doctorate abroad varied greatly. It was very low, as expected, in the United States (5.2%), was double that figure in

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Portugal (10.2%)[1] and reached 18.9% in Argentina (there are almost no foreign doctorate holders in Argentina, so the total shown in the table roughly corresponds to Argentine citizens). Second, a higher percentage of foreign citizens had earned their doctoral degree abroad: 15.2% in Portugal and 43.2% in the United States. This latter figure may be surprising given the fact that many foreigners come to the United States to prepare for their doctoral degree, but it reveals that there are also many foreigners who come to work in the United States after doing their research training abroad.

Table 11.5. Place where doctorate was received, by citizenship (percentages)

	Argentina (2005)	Portugal (2004)		United States (2003)	
	Total	Citizens	Foreign citizens	Citizens	Foreign citizens
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Received their doctorate degree in the country	81.1	89.8	84.8	94.8	56.8
Received their doctorate degree abroad	18.9	10.2	15.2	5.2	43.2

Source: First OECD/Eurostat/UIS data collection on CDH.

In addition to keeping track of cross-border movements, policy makers are interested in the reasons or motives for these movements so that they can assess how to influence and facilitate mobility. It seems that there are very different motives for international mobility, ranging from private or family reasons to professional and economic motivations. Policy mechanisms do seem to have an impact, but the extent to which this is the case is difficult to assess (Nerdrum and Sarpebakken 2006). The CDH project is thus trying to collect qualitative information on the intentions and reasons for mobility. The data for the United States offer some information on how motivation for mobility has evolved over time, and how this relates to the residential status of migrants in the country. The data from Table 11.6 show that, over the five years prior to 2003, job or economic opportunities in the United States became more prominent as a motive to move to that country than educational opportunities, compared with the preceding five years. Reasons relating to scientific or professional infrastructure also became more important. These trends were particularly marked among doctorate holders with permanent resident status. For those who had acquired US citizenship, family-related reasons also

1. In addition, 31% of all doctorate holders who received their doctoral degree abroad had also earned their previous degree abroad (and 8% of those had received their doctoral degree in Portugal).

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played an important role, although less so in the five years prior to 2003 than in the five years preceding them.

Table 11.6. Reasons given by doctorate holders for coming to the United States over the last 10 years, 2003 (percentages)

Entered the country in the last five years	Citizens of the country (by naturalization)	Foreign citizens		Total
		Permanent residents	Non-permanent residents	
Educational opportunities in the United States	28.1	14.4	26.0	23.1
Family-related reasons	20.3		6.0	8.9
Job or economic opportunities	25.0	45.6	28.5	31.7
Scientific or professional infrastructure in my field	26.6	40.0	39.5	36.4
All reasons	**100.0**	**100.0**	**100.0**	**100.0**
Entered the country five to ten years ago	Citizens of the country (by naturalization)	Foreign citizens		Total
		Permanent residents	Non-permanent residents	
Educational opportunities in the United States	19.9	27.4	38.1	31.0
Family-related reasons	32.5	10.7	4.2	10.7
Job or economic opportunities	21.7	29.2	21.3	25.0
Scientific or professional infrastructure in my field	21.1	30.1	35.6	31.3
Other reasons	4.8	2.6	0.7	2.1
All reasons	**100.0**	**100.0**	**100.0**	**100.0**

Note: Columns may not sum to 100 due to rounding.

Source: First OECD/Eurostat/UIS data collection on CDH.

Data on intention to move out of a country are also collected on an optional basis in the CDH project. The data in Table 11.7 confirm that US citizens are not very internationally mobile: only 5% of recent doctorate holders declared their intention to move out of the country, while the equivalent figures for Canadian and Portuguese citizens were 16.6% and 14.6%, respectively. Around 40% of foreign citizens in both Canada and the United States intended to leave the country in the next year, while only 25% of foreign citizens in Portugal did so.

Table 11.7. Recent doctorate holders with the declared intention to move out of the country in the next year (percentages)

	Canada (2003-2004)	Portugal (2000-2004)	United-States (2003)
Citizens	16.6	14.6	5.0
Foreign citizens	39.2	25.0	40.1

Source: First OECD/Eurostat/UIS data collection on CDH.

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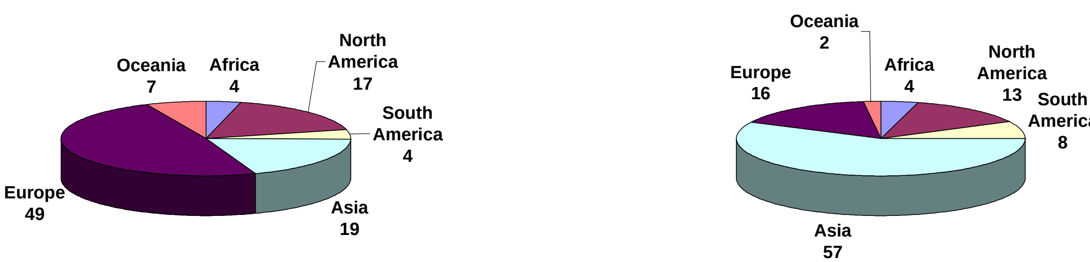
A look at the intended destinations provides more information. Among Portuguese doctorate holders who intended to move, 60% planned to go elsewhere in Europe (half of them to the United Kingdom or Spain) and 30% to the Americas (66% of these to the United States). Among doctorate holders with Canadian citizenship who intended to move, three-quarters planned to go to the United States and 18% to Europe. In the United States, the chosen destinations of doctorate holders were very different according to whether they were citizens or not. About half of doctorate holders with US citizenship had chosen Europe as their next destination and 19% Asia. Among doctorate holders with foreign citizenship in the United States, choice of destination probably reflected their origin to some extent: 57% had chosen Asia and 16% Europe (Figures 11.4 and 11.5).

Figures 11.4 and 11.5.
Intended destination of doctorate holders wishing to leave the United States, 2003 (percentages)

Citizens | Foreign citizens



Source: First OECD/Eurostat/UIS data collection on CDH.

11.5. Conclusion

This chapter has highlighted the difficulties encountered in the measurement of the international mobility of the highly skilled and in the interpretation of data on international migrations. These problems are linked to differences in national migration systems, legislation and policies, which influence the content of data sources for migration statistics, as well as the definition of immigrant populations.

The CDH project proposes improved measures of international mobility through a new methodological approach that involves cross-tabulation of data using a number of criteria relating to the origin of migrants. Thus, in "immigration countries" such as Canada and the United States, the foreign-born and naturalized population of doctorate holders would provide an indicator of long-term immigration; the foreign-born population with foreign

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citizenship and no permanent resident status would give an indication of more recent or temporary immigration; and the foreign-born population with permanent resident status could be considered to indicate an intermediate situation.

Supplementary data on date and place of doctorate received, length of stay in the country, and intentions and reasons for migration can help to determine whether a brain drain or temporary mobility is involved. Such data are also necessary for interpreting information on countries where citizenship is harder to acquire and where the notion of permanent or non-permanent residence does not apply. The CDH project is trying to gather such data and to construct indicators of international mobility.

This chapter demonstrates that there is a way to build relevant indicators of international mobility, notably by differentiating between migration-type and mobility-type indicators. It also argues that collecting information on the intentions and reasons for migration and mobility is necessary, since policy mechanisms may need to take into account the wide variety of individual considerations and motivations involved.

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Part Five

MEASURING CROSS-CUTTING AND EMERGING STI ISSUES

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Chapter 12

BIOTECHNOLOGY: FROM MEASURES OF ACTIVITIES, LINKAGES AND OUTCOMES TO IMPACT INDICATORS

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12.1. Introduction

The existing rhetoric on the future benefits of biotechnology could be summarized as: biotechnology is the next technology wave that will deeply transform the economy and society by providing products and processes that will solve health problems, feed the world with new agricultural products, heal the environment and provide sustainability. Beyond the rhetoric, the indicators of biotechnology activities reveal an emerging phenomenon that is still relatively small. Many actors from the private sector, governments and universities are convinced of the future success of biotechnology. A recurring policy question is: What evidence provides a solid basis or argument for government to invest in biotechnology?

The last decade saw the emergence of a wealth of data and statistics attempting to portray the development of biotechnology. This work is largely summarized in *A Framework for Biotechnology Statistics* (OECD 2005), which provides guidance and standards for the measurement of biotechnology activities. It should be noted that most of the data currently collected focuses on the activities, linkages and outcomes of firms engaged in innovation activities through the use of biotechnology.

Activity indicators focus on data collected on actors (*who*), performing an activity (*what*), in a location (*where*), to fulfill an objective (*why*). Linkage indicators show how many resources have been committed and how actors are connected to other social or economic organizations and institutions. Outcome indicators provide measures of the results achieved. Most of these indicators are available in Canada through the Biotechnology Use and Development Surveys conducted by Statistics Canada (Statistics Canada 2007).

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Biotechnology impact indicators can be related to indicators of socio-economic change. An impact indicator may be a ratio and typically tracks a change. For example: X% of the vaccine market is composed of products developed using biotechnology, compared with Y% in a previous period; or X% of total research and development (R&D) is performed using biotechnology; or the occurrence of a disease, expressed as a percentage of the population, is diminished by Y% after the introduction of a genetic therapy. In many of these cases, socio-economic change follows the introduction of the biotechnology activity.

Typical problems associated with impact indicators related to an emerging technology are twofold. First, when compared with long-term trends observed in major socio-economic impact indicators, the magnitude of biotechnology-related indicators, such as revenue generated and overall employment, appears relatively small, if not negligible. This type of impact indicator captures a net wealth effect – that is, the difference between new economic activities generated and economic activities discontinued as a result of the emergence of the new technology. Second, most existing impact indicators do not take into account substitution effects, such as substitutions of inputs, changes in processes leading to the production of goods and services, and substitutions in finished products. This chapter argues that a significant part of the impact of biotechnology is the result of substitution effects. Measuring such impacts remains a challenge for statisticians.

This chapter also focuses on impact indicators that would be relevant to policy analysts and decision-makers and discusses what transformations of or additions to existing measures of activities, linkages and outcomes are required to allow the construction of impact indicators.

12.2. Overview of existing indicators and the current state of international comparability

The first attempts to measure biotechnology focused on R&D activities in the late 1980s. Early measurement showed rapid increases in R&D spending, almost doubling every second year (Statistics Canada 1997). This was a sign that businesses were adopting biotechnology.

Biotechnology data collected through existing R&D surveys are usually fairly limited, providing information on numbers of actors and personnel involved and money spent, broken down by firm size, industrial sector and geographical location. A better understanding of the technology adoption and innovation process associated with biotechnology requires more sophisticated data collection instruments.

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In the late 1990s, the statistical offices of some Organisation for Economic Co-operation and Development (OECD) member countries (Canada, New Zealand and France) initiated their first dedicated surveys of biotechnology activities in the industrial sector. The main focus of these surveys was firms that were actively engaged in the use of biotechnology for R&D, production and innovation purposes.

Generally, the questionnaire used to collect the information could be divided into three parts. The first part determined whether the surveyed firm was engaged in biotechnology activities and, if so, in what way. Typically, respondents were given a list from which to indicate their use of specific biotechnologies. Similar techniques were used to determine the areas of application for biotechnology or innovative behaviour. Responses to the questions allowed the building of the final population of biotechnology-active firms.

The second part of the questionnaire dealt with standard indicators of firm characteristics, such as firm size, geographical location, industrial classification, ownership and structure. Determination of these characteristics required the collection of general quantitative information, such as on employment and revenue. Most other types of information were qualitative in nature and could be used to segment the respondent population for the purposes of analysis.

The third part of the questionnaire requested both qualitative and quantitative information oriented towards specific policy and analytical questions. These questions were often similar to those encountered in the measurement of innovation and described in the *Oslo Manual* (OECD/ Eurostat 2005). They covered the role of alliances and partnerships, success factors and impediments, management of intellectual property (IP) instruments, and business strategies.

Because many aspects of biotechnology are related to health, food and the environment, regulation plays an important role. It also creates additional lags in the innovation process. As a consequence, raising capital is an important factor to consider, both for established firms that require enough financial capital to undertake the commercialization process and for emerging firms that need to survive until the commercialization of their first products. Therefore, biotechnology surveys put more emphasis on collecting information on raising capital, covering attempts to raise it, success in raising it, amounts raised, sources of funds and obstacles encountered.

In recognition that innovation is becoming a more collective endeavour, much attention was given to alliance and partnership formation. There are generally two reasons for the need to enter into collaborative arrangements: managing risks and accessing capacities. Risks can be financial or related to

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market uncertainties. For the purpose of biotechnology surveys, accessing capacities included access to complementary R&D knowledge, IP, production facilities, distribution networks and regulatory management.

Concurrently with these survey developments, the OECD established an Ad Hoc Working Group on the Measurement of Biotechnology Statistics, reporting to the Working Party of National Experts on Science and Technology Indicators (NESTI) and to the Working Party on Biotechnology (WPB).

The Ad Hoc Working Group met five times between 2000 and 2004. It established a statistical definition for biotechnology and proposed ways of applying the definition in R&D surveys, dedicated biotechnology surveys and patent classification. It also proposed a list of potential indicators, collection guidelines, classification schemes, and model questions and surveys (see OECD 2005).

In 2004, the OECD hosted a workshop on the economic impacts of biotechnology. The summary document made some interesting points about the measurement of impacts. Most countries had focused on the biotechnology activities of dedicated firms or early adopters of the technology. However, as a generic and enabling technology, biotechnology brings many changes to a broad spectrum of economic activities that cannot be effectively monitored by a sole focus on the early adopters. Biotechnology is a tool used to develop many applications, which, once developed, may have significant impacts that will not necessarily be linked back to the original use of biotechnology. Therefore, the impacts of biotechnology may potentially be underestimated.

Another interesting point made relates to the focus on biotechnology itself, from two different perspectives. First, biotechnology tools and applications that are developed and used can vary quite substantially according to application domains. There are some overlaps, but also important differences, in the techniques used for health, agri-food or industrial applications. Recent Canadian experience in conducting a bio-products survey showed that firms in the sector outside health and agri-food do not necessarily recognize themselves as coming under the biotechnology umbrella. Biotechnology can be very sector-specific. Second, biotechnology, particularly in the industrial sector, may only be a tool in a more fundamental process that consists of progressively substituting existing petroleum-based applications with applications based on a new and different use of biomass, a renewable resource.

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The measurement of biotechnology impacts will need to go beyond assessment of key activities performed by the actors directly involved in the use of the technology to encompass impacts on the demand and consumer side.

12.3. Is biotechnology important?

Biotechnology is often described as a generic and enabling technology – that is, a set of techniques that enables a new wave of innovations to be spread across many industries. The first key question is: How important is it? One way to recognize the early stages of a technology revolution statistically is through R&D activities. In 2003, Canadian industries spent $1.5 billion on biotechnology-related R&D. This represented 12% of total industrial R&D, and was less than the expenditure for information and communication technologies (ICTs) ($5.2 billion), but more than for aerospace ($900 million) and automobile industries ($600 million). Biotechnology R&D expenditure has experienced a two-digit growth rate since 1987. However, when biotechnology revenue or employment is compared with the rest of the economy, the ratios are very small. If biotechnology is important, it is not yet because of a tangible overall impact on the economy.

The second question is: How widespread is it? Although biotechnology R&D is clearly significant and is carried out in several industries, most of it occurs in health and food applications. It is also found, but to a lesser extent, in natural resources, environmental industries, informatics and industrial applications. Why is this? One explanation could be that, as the technology is still in its early stages, biotechnology activities occur mainly in areas where applications can be developed more quickly, and they are entering other industries more slowly. This is not an entirely satisfactory explanation, since the regulation process required to get a product on the market causes a lag in the areas where biotechnology applications are mainly being developed.

Another explanation relates to the way in which biotechnology has been defined so far. For statistical data collection, biotechnology is described as a set of techniques that could be used in R&D, in production and for environmental applications. This description has proved useful for data collection from firms directly involved in the use of biotechnology-related techniques. The OECD single definition of biotechnology is broad: "The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services." This definition should

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always be accompanied by a definition from the list of biotechnology techniques given on the OECD Web site.

At the heart of the OECD definition is the use of science and technology (S&T) in conjunction with material of living origin. Most of the techniques found in the OECD list deal more with transformative processes based on the use of living material. The list tends to disregard the alteration of living material through the use of more conventional techniques. Is the list, which is currently used by OECD countries to capture biotechnology activities, therefore potentially biased towards classical applications of biotechnology, such as health and food? If so, this would imply a potential underestimation of the breadth of activities coming under the umbrella of biotechnology.

To address this potential bias, in 2004 Statistics Canada conducted the first survey of the development of bioproducts in the industrial sector (Statistics Canada 2005). The basic firm characteristic was the novel use of feedstock as an input in the development of new products and processes rather than the use of specific techniques. One finding from this initial survey was that firms involved in more traditional economic activities may have been engaged in activities that could be characterized as biotechnology, but that they did not necessarily recognize them as such.

Is biotechnology an important phenomenon? The level of R&D investment suggests that it is. However, its impacts in terms of dispersion or changes in economic structures or activities largely remain to be observed, measured and analyzed.

12.4. Potential impact indicators

What is meant by impacts? Statistics Canada's framework for a statistical information system (Statistics Canada 1998) makes a distinction between outcomes and impacts. Outcomes are the direct results of an S&T activity; impacts are those consequences for the social, economic, political and environmental system, and for science, that take longer to emerge and are often more difficult to detect and attribute to their origin.

The document also makes a distinction between impacts that affect the socio-economic system and are the result of the introduction of an innovation, and impacts that affect the environment surrounding S&T activities and result from changes in social, economic or political organization. This requires further discussion.

"Innovation" is a widely used term that, strictly speaking, describes the introduction to the market of a new product, process, organizational activity or market development (OECD/Eurostat 2005). It is also used more broadly to describe the introduction, adoption and diffusion of new scientific and

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technological advances. The concept of impact of innovation is a little too narrow to describe the effect of emerging and enabling technologies adequately. The latter effect could be described as a stream of innovation resulting from a combination of advances in S&T and socio-economic conditions that allows the emergence of a new technological system – that is, a system that has significant impacts on economic inputs (material, labour, capital and energy), on organizations, structures and institutions, and on consumer behaviour.

Single innovations may have large impacts – the development of the Internet is one example – but they are better described and understood when put in the broad context that allowed their emergence. In the case of the Internet, this was the development of ICTs resulting from the introduction of computers and communication protocols.

The measurement of emerging technologies differs slightly from that of innovation, although the initial focus is still the firm. In innovation surveys, a firm is considered innovative if it has introduced to the market new or significantly improved products or processes. The characteristics of innovative firms are then compared with those of non-innovative firms. Analysis attempts to assess the effect of innovative behaviour on firms' overall performance, and to establish whether some firm or innovation characteristics are more successful than others.

Surveys of emerging technologies focus on firms' adoption of generic technology. So far, the aim has been not to compare the overall performance of adopters and non-adopters, but to provide indicators of the relative market penetration of emerging technologies. Innovative behaviour is measured as well, but with the purpose of distinguishing between newly adopted technologies and similar pre-existing technologies. For instance, fermentation processes, strictly speaking included in biotechnologies, have been used in industry for decades, if not centuries in some cases. The measurement of innovative behaviour is used in emerging technology surveys as a means to restrict the focus to new and innovative usage of technologies.

Focusing on adoption (market penetration) rather than on innovation (firm performance) allows a broader assessment of the impacts of S&T changes. These impacts can be divided into the following five categories:

- Economic (the sphere of all market transactions, including those concerning non-tangible assets);
- Social (the sphere of all social relations, including the policy environment);

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- Environmental (the physical environment, consisting of air, water, soil, radiation, noise and living organisms other than human);
- Health (human well-being, including personal health and food supply); and
- Ethical and cultural (the conflict of values and cultural changes brought by emerging technologies).

So far, national statistical agencies have focused mostly on the economic impacts of emerging technologies, but there is a role for them in the measurement of other types of impacts. In the case of biotechnology, little has been attempted in these areas. The remainder of this chapter therefore focuses more on economic impacts.

Economic impacts can be divided roughly into two categories: macroeconomic and microeconomic. The former relates to broad economic aggregates such as productivity, economic growth, industrial structure, trade and the labour market; the latter concerns business conditions and performance, changes in price and cost structures, and the transformation and substitution of inputs. Following is a breakdown of potential areas for developing economic impact indicators.

12.4.1. Macroeconomic impacts

12.4.1.1. Changes in productivity

The adoption of emerging technologies results in input transformation and substitution, and the introduction of new products and processes that, overall, alter productivity measures. The impacts of such changes on global productivity indicators are macroeconomic, although the understanding of the processes governing input transformation and substitution belongs, strictly speaking, in the category of microeconomic impacts. An important challenge lies in the measurement of the output, especially if part or all of this output is intangible.

12.4.1.2. Economic growth

Economic growth could be observed at the level of the economy as a whole (gross domestic product (GDP)) or at the sectoral level. At the sectoral level, comparison could be made to overall economic growth or to growth in other sectors.

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12.4.1.3. Changes in industrial structure

Changes in industrial structure refer to the transformation of existing industries, the emergence of new industries or change in the relative weight of each industry in the economy.

12.4.1.4. Changes in trade

This refers to changes in commodity-level trade. Examples related to biotechnology include measures of genetically modified crops, imports and exports of biotechnology products, and market penetration of biotechnology products (measured as market share).

12.4.1.5. Changes in the labour market

The adoption of biotechnology requires different skill sets, which involve knowledge of biology and biochemistry. As adoption increases, changes in the distribution of these characteristics could be monitored in the labour force. In addition, longer-term changes in employment level by sector could be monitored, especially if a greater demand for biomass related to the adoption of biotechnology occurred. The changes in the characteristics of the labour force are likely to be more pronounced in the urban rather than in the rural population.

12.4.2. Microeconomic impacts

12.4.2.1. Firm changes

Biotechnology is perhaps one of the first generic technologies to emerge directly from university laboratories. Many firms are spinoffs from university research (Byrd 2002). Some of these firms survive and grow; others disappear, move or are absorbed by other firms; still others have to change their activities or perish. This is an area of interest to those forming industrial policies aimed at maximizing the benefits for a country.

12.4.2.2. Changes in price and cost structures

These are more difficult to assess, since many firms do not maintain separate accounting records for products developed through the use of biotechnology (or other generic technology). However, comparisons could be made between cost structures for firms offering substitute products using biotechnology and those for firms producing similar products using traditional techniques. This should be done over many years to avoid distortions related to the fact that, as biotechnology is an emerging technology, there may be initial development costs. These may skew the

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cost structure upward, especially in comparison with a fully developed technology incorporating years of productivity improvements.

12.4.2.3. Competitiveness

This relates to a firm's ability to survive, compete and grow in a highly competitive environment. Two types of impact indicator could be developed: the relationships between prices and cost structures and the ability of firms to compete, as measured by market share; and the link between firm strategies and ability to compete.

12.4.2.4. Changes in competitiveness conditions

Although similar to the previous category, this area of indicator development relates to links that could be established between firms' strategies and economic conditions, expressed in terms of geographical location, proximity to market, proximity to supply sources (biomass) and proximity to knowledge centres (universities and research institutes).

12.4.2.5. Substitution of inputs

For generic technologies, an interesting area to monitor is the substitution of inputs. It could be raw material substitution, such as the substitution of biomass products for petroleum, energy source substitution or changes in labour composition. An example of the latter is the progressive replacement of chemists with biochemists or biologists. Workforce specialization may change through the hiring of new personnel or the retraining of existing employees.

Table 12.1 provides a summary of these potential economic impact indicators, broken down by category.

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Table 12.1. Summary of economic impact indicators

Category		Indicators
Macroeconomic impacts		
	Changes in productivity through innovative products and processes	
		Productivity index by sector
	Economic growth	
		Growth ratios, economy-wide and sectoral
		Growth ratios, biotechnology vs. non-biotechnology firms
	Changes in industrial structure	
		Revenue shares, by industry, biotech. vs. non-biotech.
		R&D shares, by industry, biotech. vs. non-biotech.
		Firms' concentration ratios in terms of revenue, employment and R&D
		Transformation, rise and decline of industries
	Changes in trade (changes in input-output structure)	
		Changes in input-output patterns
		Import and export indicators, by industry and by commodity
	Changes in the labour market	
		Structure of labour market, by occupation
		Educational attainment and field of study
Microeconomic impacts		
	Business creation, growth, death, merger and change of activity	
		Number of firm creations, deaths, mergers, acquisitions
		Firm characteristics: age, ownership (public vs. private)
		Recording of events related to firm development: venture capital, initial public offering (IPO), licensing, alliance formation, product to market
	Changes in price and cost structures	
		Price of biotechnology product and price of substitute, non-biotechnology products
		Comparative cost structures of biotechnology vs. non-biotechnology firms
	Competitiveness	
		Biotechnology firms' market share and changes in market share
		Time series analysis of firm growth correlated to firm characteristics
	Changes in competitiveness conditions	
		Geographical location
		Proximity indicators
	Substitution of inputs	
		Input structure for raw material, energy sources

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12.5. Statistical requirements for the measurement of impacts

The production of the potential economic impact indicators listed above would involve many changes to the statistical collection instruments currently used and the linkage of existing databases to facilitate the required analytical program. In many cases, new data would be required; in others, changes to the way data are collected and to existing classifications would be needed. Following are some of the changes that would be required.

12.5.1. New surveys or changes to existing surveys

To assess the impacts of biotechnology and other generic technologies, specific surveys are required for the various sectors of the economy. Currently, in Canada and in many OECD countries, information is collected on biotechnology-related R&D activities. Many countries conduct industry-specific biotechnology surveys, which cover mainly the activities of firms using biotechnology for innovative purposes; a few countries have conducted an assessment of biotechnology activities in the government sector; the higher-education sector is barely covered. Biotechnology-related services are rarely surveyed.

A first step would be a progressive increase in the coverage of the sectors surveyed. This would require more work to establish adapted definitions, methodologies and classifications. The OECD is already engaged in a process to adapt and establish the required definitions and methodologies for the government sector, and will follow the same process for the higher-education sector.

Statistics Canada recently explored a new area with two surveys on bioproducts. While biotechnology surveys are based on the use of a particular technology, bioproducts surveys focus on the use of a specific input: the use of biomass for innovative purposes. There is a significant overlap between the two types of survey. Biotechnology techniques may be used for the development of bioproducts, but they are not a necessary condition. However, in the end, the innovations emerging from biotechnology or bioproducts development have in common the use of living organisms, which is a key part of the OECD definition of biotechnology. These surveys should not be considered as separate endeavours, but rather as part of an effort to understand the changes in the economy triggered by the emergence of biotechnologies.

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12.5.2. Linkage of existing databases

In attempts to isolate and analyze the emergence of biotechnology and to build comparative analyses based on the wealth of information and indicators currently available for the whole economy, the main drawback is the absence or lack of data allowing the construction of value-added indicators and a productivity index. There are two main reasons for this. First, production data to support System of National Accounts (SNA) indicators are already collected through regular production surveys. Duplicating these efforts would impose an undue burden on respondents. It is possible to link surveys in an attempt to build value-added indicators. However, the main problem is that existing data would not be biotechnology-specific, unless some of the firms were entirely dedicated to biotechnology. Second, the collection of biotechnology-specific production data would have to be based on the assumption that respondents could provide such data. This would be possible for firms that are completely dedicated to biotech-nology, but would be less likely for firms in which biotechnology is only part of their activities, as there is no indication that respondents would maintain separate accounting records. However, by linking survey databases, it might be possible to perform analytical work on value-added and productivity indicators.

12.5.3. Changes in the classification system

Building biotechnology-specific trade indicators would require changes in existing commodity classifications. Because of trade restrictions on genetically modified crops imposed by many countries, it would be useful to find ways to create biotechnology- and bioproducts-specific categories that would allow the collection of trade statistics for biotechnology. However, this would be a significant task, as these classifications have to be internationally harmonized. A first step would be to assess the capacity to collect such information. This assessment would form the basis for national and international discussions on revisions to commodity classifications.

Before or during the process of changing existing surveys and classifications, important analytical work would need to be undertaken to link existing micro-data from biotechnology surveys to other surveys. For instance, biotechnology surveys could be linked to industrial R&D surveys, innovation surveys or regular industrial production surveys. This would substantially augment the capacity to extract valuable information.

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12.6. Conclusion

While many recognize that biotechnology is an important transformative technology, there is legitimate public concern about some existing or potential biotechnology applications. This makes policy choices more difficult to make and to sell. Political support is uneven from country to country. Meanwhile, as shown by the level of investment in R&D, biotechnology continues to make progress and to be diffused throughout the economy. This requires monitoring.

Increasing current knowledge of living organisms, biotechnology allows not only the transformation of existing processes, but, more importantly, the substitution of inputs from non-renewable resources towards the use of biomass, a renewable resource. The result is a process that is more sustainable.

Existing surveys provide important information on the biotechnology-related activities performed by the industrial sector and, to some extent, by governments. More information is needed on such activities in the higher-education sector and on biotechnology-related services.

With more use of biomass, product and process innovation may have substitution effects in the economy that need to be monitored if countries wish to maximize the economic and social returns. As often observed, large substitution effects in the economy can trigger employment and capital losses in some industrial sectors, and job creation and capital formation in others. An important motive for monitoring these changes is the need to minimize the costs associated with them.

This chapter has suggested some areas for indicator development applicable to an emerging and transformative technology, biotechnology, but they may also be considered for other generic technologies. Nanotechnology is a potential candidate.

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Chapter 13

A FRAMEWORK TO MEASURE THE IMPACTS OF INVESTMENTS IN HEALTH RESEARCH

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13.1. Introduction

In 2005, the Canadian Institutes of Health Research (CIHR) began work to develop a framework and indicators to measure the impacts of investments in health research. The development process included national and international consultations that involved academics, government, research agencies, and health organizations and associations. Through the process, participants identified different stakeholder groups with an expected interest in impact information and their individual interests or information needs. The resulting framework classifies indicators into four broad categories[1] that encompass a range of impacts. This chapter provides details about the indicators and potential data or information sources. It also discusses some of the anticipated challenges associated with impact measurement, including the recognition that certain impacts will not easily be attributable to specific organizations or activities. Although the framework has been designed to collect impact measures relevant to CIHR, the collaborative and consultative process through which it was created makes CIHR confident that others will find it applicable to their specific needs. As CIHR and other stakeholders begin to use the framework, further learning and improvement in methods or approaches for measuring the impacts of health research funding are anticipated.

13.2. Health research funding in Canada

Canada has three federal granting councils to fund and promote research. CIHR is responsible for health research, although some health research funding is also provided by the other two granting councils and by

1. The original framework included five categories, which have now been collapsed into four.

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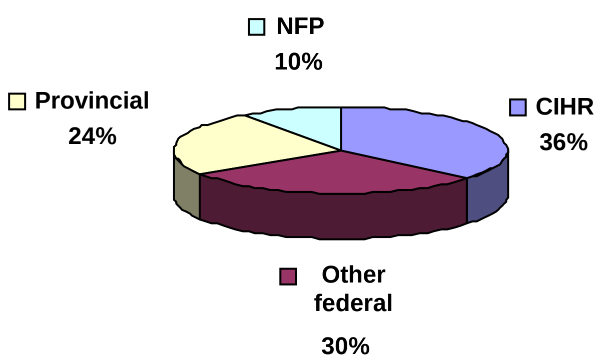
national agencies dedicated to health or innovation.[2] Funding for research infrastructure and a share of indirect costs are provided by two separate agencies.

Nine of the Canadian provinces also have specific provincial health research funding agencies.[3] The not-for-profit (NFP) sector includes many philanthropic and disease-specific charities. Funding agencies from three sectors – federal, provincial and NFP – often collaborate to sponsor research within their mandates.

The distribution of health research funding by sector is shown in Figure 13.1. Statistics Canada estimates for gross domestic expenditure on R&D (GERD) include funding from these three sectors, as well as from higher education, business enterprise and foreign sources.

Figure 13.1. Distribution of health re search funding in the public and NFP sectors, 2003-2004



Source: CIHR (2006).

2. Some of the national agencies that provide some health research funding include Genome Canada Ltd., Health Canada, the National Research Council, the Canadian Health Services Research Foundation, the Canadian Agency for Drugs and Technologies in Health, and the Canadian Foundation for Innovation.

3. See the National Alliance of Provincial Health Research Organizations (NAPHRO) (*www.ahfmr.ab.ca/naphro.php*).

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13.3. CIHR

CIHR was created in 2000 with a mandate "to excel, according to internationally accepted standards of scientific excellence, in the creation of new knowledge and its translation into improved health for Canadians, more effective health services and products and a strengthened Canadian health care system" (the *CIHR Act*; *www.cihr-irsc.gc.ca/e/22948.html*). A full description of CIHR is available at *www.cihr-irsc.gc.ca/e/24418.html*, and a summary is given here in Figure 13.2.

Figure 13.2. CIHR operating model

Mandate	
Improved health for Canadians	
More effective health services and products	
Strengthened Canadian health-care system	
Core objectives	
Advancing health knowledge through excellent and ethical research	
Translating health research into action	
Training and career development	
Research themes	
Biomedical research	Health services and policy research
Clinical research	Population and public health research
CIHR institutes	
Aboriginal Peoples' Health	Human Development, Child and Youth Health
Aging	Infection and Immunity
Cancer Research	Musculoskeletal Health and Arthritis
Circulatory and Respiratory Health	Neurosciences, Mental Health and Addiction
Gender and Health	Nutrition, Metabolism and Diabetes
Genetics	Population and Public Health
Health Services and Policy Research	

Increased investments in and through CIHR in recent years have led to a need to demonstrate accountability and value for money.

At CIHR, performance measurement data are collected routinely during the implementation of initiatives, programs and projects. The data are reported on a regular schedule and are ultimately used to assess performance and progress, to guide program adjustments and to inform stakeholders. Some examples of routine performance measurement data collected at CIHR

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include: distribution of budget expenditures; details of research grants (*e.g.* number, value, success rates); training (*e.g.* number, value, success rates for training awards); and commercialization (*e.g.* number of patents, number of intellectual property (IP) licences and of companies formed). Data are collected from multiple sources, including administrative databases, surveys of stakeholders and surveys of funding recipients.

While CIHR regularly evaluates its individual programs and has documented the benefits of specific CIHR-funded research projects, to date there has been no comprehensive or overall assessment of their outcomes in terms of scientific, health and economic impacts.

13.4. Impact framework development

Several funding agencies from across the world share CIHR's interest in assessing the impacts of health research in order to be more accountable. Understanding the impacts of research funding is one means of ensuring value for money (*i.e.* that research dollars are well spent). However, measuring the impacts of health research poses a challenge for research funders.

There is some ambiguity in the way the terms "impact" and "outcome" are used. Sometimes, they are used interchangeably; at other times, "outcome" is used to refer to a mid-term achievement and "impact" to a longer-term achievement (Hovland 2007). Impact has been categorized as either instrumental or conceptual (Davies, Nutley and Walter 2005). Instrumental impact has been defined as a clear connection between an individual research study and specific products or decisions and resulting effects. It tends to occur rarely and should not be the sole gauge of success. Conceptual impact occurs more frequently, when research contributes to advancing knowledge and informing decisions, and potentially leads to broader effects when findings are implemented (Weiss 1977). Both types of impact are difficult to measure and to attribute to specific activities or inputs.

In 2005, building on its performance measurement and evaluation frameworks, CIHR set out to develop a framework to measure the impacts of its investments in health research and capacity development and to begin to identify robust indicators that could be used to establish benchmarks and track progress over time. In early 2005, CIHR convened a group of international and Canadian experts to identify similarities in the major objectives of funding agencies, to review the current state of knowledge about measuring the impacts of health research and to provide advice on the creation of a conceptual framework.

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The categories within which to measure impact were adapted from the payback framework developed by Martin Buxton and his colleagues at Brunel University (Buxton and Hanney 1994), and Buxton was an active participant in the development of the CIHR framework. The framework was adapted to account for identified stakeholder issues and existing performance measurement activities.

13.4.1. Stakeholders

Stakeholders were defined as those sectors that would probably be interested in the demonstrated impacts of research funding. The stakeholder sectors for health research impact information are summarized in Table 13.1. Some issues were unique to particular stakeholder groups, while others were shared by many or all sectors. For example, academic excellence was of interest mainly in the higher-education sector, while an interest in health status was shared by all sectors.

Table 13.1. Stakeholder sectors for health research impact information

Stakeholder sector	Issue/interests
Higher education	• Academic excellence • Knowledge creation • Capacity building • Health status
Health care	• Prevention strategies, diagnostic potential and effective treatments • Effectiveness and efficiency of resources used in health systems • Health status
Public	• Health status • Health care • Response to public-health threats • Efficiency and sustainability of health systems
Business	• Commercial potential • Contribution to economic growth and productivity • Health status
Government	• Public health and response to public-health threats • Health status • Contribution to economic growth and productivity • Efficiency and sustainability of health systems
Health research funding	• Health status • Knowledge creation • Research capacity • Knowledge translation (KT) • Contribution to economic growth and productivity

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In designing the framework, CIHR sought first to identify generic types of impact information to address stakeholder interests, and then to identify indicators to measure benchmarks and progress. For example, health impacts would be oriented to a system of health status indicators developed over the last decade and would be tracked annually (CIHI 1999; Health Canada 2004).

After consideration of stakeholder issues, new indicators were identified to assess and demonstrate how research contributes to health, social and economic impacts. The resulting framework was vetted at a meeting in May 2005 with federal government representatives, provincial research agencies, health-care organizations and academics. The framework and draft indicators were then published on the CIHR Web site in January 2006 (*www.cihr-irsc.gc.ca/e/documents/meeting_synthesis_e.pdf*). Since that time, CIHR has begun to populate some of the indicators. This has led to refinements and updates, which are included in this chapter.

13.5. The CIHR impact framework

The framework details the key anticipated and desired categories of health research impacts, and some preliminary indicators with potential data sources. The impact categories, as adapted for the CIHR framework, are:

- *Advancing Knowledge*: this category includes discoveries/breakthroughs, contributions to the scientific literature and the development of skilled researchers.
- *Informing Decision-Making*: this category includes the impacts of research in the areas of public, clinical and managerial decision-making, practice and policy.
- *Health Impacts*: this category encompasses advances in prevention, diagnosis, treatment and palliation.
- *Economic Impacts*: this category is divided into three subcategories (Buxton, Hanney and Jones 2004): commercialization of discoveries; direct cost savings; and human capital gains.

Social impacts are recognized as important, but it is not yet clear whether it is possible to ensure the capture of these impacts through each of the existing categories or whether a separate category is necessary. For example, improved health is a health benefit, but it is also a benefit to society; similarly, cost savings to the health system have both economic and social impacts (Sharpe and Smith 2005; Torjman and Minns 2005). The possible approaches to capturing the social impacts of health research continue to be explored.

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Table 13.2. Preliminary indicators of health research impacts and potential sources of information

Advancing Knowledge	
1. Number of discoveries/breakthroughs resulting from CIHR-supported research 2. Number of Canadian health research publications 3. Number of publications resulting from CIHR-supported research 4. Impact of publications as demonstrated by citation intensity (citations/GDP) compared with wealth intensity (GDP/population) 5. Percentage of Canada Research Chair (CRC) holders attracted to or retained in Canada 6. Number and type of Ph.D. graduates in Canada by year 7. Percentage of Ph.D. graduates in Canada planning post-doctoral work in health	Bibliometric studies End of grant/research results reporting CIHR program evaluations Citation impact analysis Databases of CRC holders Data available through Statistics Canada (*i.e.* census and survey data) CIHR performance management data
Informing Decision-Making	
1. Public policies informed by CIHR and CIHR-funded research 2. Clinical practice informed by CIHR-funded research 3. Health system management decisions informed by CIHR-funded research 4. Research, policy and/or practice agendas influenced by funded research and/or CIHR institutes 5. Impact of Canadian health research publications 6. Impact of publications resulting from CIHR-supported research	Case studies (multi-method special studies) End of grant/research results reporting CIHR program evaluations CIHR performance management data Research user surveys Citation impact analysis
Health Impacts	
1. Research study participants' health status affected by participating in CIHR-funded research 2. Population health status influenced by CIHR-funded research 3. Potential years of life lost (PYLL) for target disease categories (*e.g.* cancer, circulatory disease) influenced by CIHR-funded research 4. Health-related quality of life influenced by CIHR-funded research	Case studies (multi-method special studies) End of grant/research results reporting Statistics Canada data Special studies to establish links to health research CIHR performance management data Analyses of publications
Economic Impacts	
1. Number and nature of patents, spinoff companies and IP licences influenced by CIHR-funded research 2. Income from IP commercialization 3. Commercial use of research funded by CIHR's commercialization programs 4. Cost savings influenced by CIHR-funded research 5. Human capital gains, including productivity influenced by CIHR-funded research	End of grant/research results reporting Statistics Canada data Case studies (multi-method special studies) Technology assessment special studies Collaborative studies with Health Canada and Statistics Canada

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Indicators within each framework category are shown in Table 13.2. Examples of possible results, data availability and approaches for developing new data sources are subsequently discussed.

Several of the indicators identified in Table 13.2 will need to be developed further through special studies, as the information required is not routinely collected. These studies will vary in complexity and in the degree of collaboration required with other agencies. CIHR institutes can carry out case studies of strategic research initiatives, for example, at suitable intervals following the completion of a strategic research project. The immediate importance of the approach illustrated in Table 13.2 is to clarify the types of information that are desirable, identify how they fit within a conceptual framework and determine potential sources of information.

13.6. Framework: current examples

13.6.1. Advancing knowledge

Discoveries and breakthroughs: CIHR is designing an end of grant/research results reporting system to capture knowledge creation outputs from individual research grants. It is anticipated that, once launched, this system will provide data for this indicator. Data will also be derived from case studies and from follow-up with funded researchers.

Number of Canadian health research publications (Table 13.3): CIHR currently has some information on publications produced by CIHR-funded researchers from their curricula vitae, although it is recognized that a portion of these would probably not be directly attributable to CIHR funding. General publication trends for health research in Canada are being used until the end of grant/research results reporting system is operational and CIHR-specific data are available. A study in the United Kingdom found that Canada ranked sixth among the nations of the world (behind the United States, the United Kingdom, Germany, Japan and France) in its share of total publications in 8 000 journals between 1993 and 2003 (OST 2004; King 2004).

Table 13.3. Publication impacts

Indicator definition	Results
Canadian publications/total publications	Canada produces about 5% of the world's health research literature at an annual rate of 14 000–15 000 publications. In 2004, this represented roughly 6.7% of total publications on health among the G8 nations (Observatoire des sciences et des technologies 2005).

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The two indicators above vary in terms of sophistication. The second would be expected to be a more contextual measure of scientific output, since it takes into account a country's level of economic development. But sophistication can come at the cost of reduced comprehension for a broad audience. Other bibliographic indicators can also be used: for example, the Thomson Scientific *Journal Citation Reports* to assess the impact of specific publications (*www.thomsonisi.com*).

Researchers attracted to or retained in Canada: Sources of information include Statistics Canada surveys (Table 13.4) and periodic evaluations of the CRC program.

Table 13.4. Human capital

Indicator definition	Results
Number and type of Ph.D. graduates* in Canada by year.	Canada ranks fifth in the world for the proportion of the population with a Ph.D. (King 2004).
Percentage of Ph.D. graduates in Canada planning post-doctoral work in health.	A Statistics Canada survey in 2003–2004 found that 64% of graduates in the life sciences planned to pursue post-doctoral studies (data taken from Gluszynski and Peters 2005, 14).

*Health research is not restricted to specific disciplines; thus, the overall number/type of Ph.D.'s is a relevant measure for Canada.

13.6.2. Informing decision-making

The indicators listed for this impact category (research, public, clinical, managerial and policy decisions influenced by funded research and/or CIHR institutes) need to be put in context (Table 13.5). In other words, what decisions have been influenced and what role has the research played? Both strategic funding initiatives and investigator-initiated research will contribute to this category. Follow-up surveys or focus groups can be designed to determine how well specific research has informed decisions. These activities can be complemented by ongoing efforts to determine how effective KT efforts have been in affecting practice or policy.

Compared with the impact of targeted research, the impact of curiosity-driven research may occur less often and may take longer to be observed. CIHR intends to develop a system to monitor actively the output of all investigator-initiated research and to undertake special studies to identify the influence of this type of research on decision-making.

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Table 13.5. Research impacts

Indicator definition	Results
Research influence as demonstrated by citation intensity.	In terms of citation intensity, Canada is among the top eight countries, all of which are above the curve that defines citation intensity as a function of wealth intensity. Canada and the United Kingdom are the only two G8 countries above the curve (King 2004).
Extent to which funded research and/or CIHR institutes have influenced the research, policy and/or practice agendas in their communities	A recent survey found the following. • There was broad agreement among funded researchers that the institute with which they were affiliated had contributed to developing capacity in terms of people (84%), the research environment (83%) and research excellence (91%). • Ninety-three percent of CIHR-funded researchers and 90% of non-CIHR-funded researchers believed that CIHR has set a national research agenda; and 95% and 90%, respectively, felt that this agenda is the appropriate one.
Development of scientific and public policy guidelines/standards	• Decision-makers used results from syntheses of CIHR-commissioned research in 2005 to determine benchmarks for medically acceptable wait times in five priority areas. • Guidelines for human embryonic stem cell research. • Privacy and confidentiality in health research.

13.6.3. Health impacts

Participants in clinical studies experience individual health impacts. CIHR intends to demonstrate the health impacts for participants in CIHR-funded research. For example, for 60% of participants in the intervention group of the DREAM (Diabetes REduction Assessment with ramipril and rosiglitazone Medication) trial diabetes was prevented (Gerstein *et al*. 2006). Study findings have the potential for a population health impact if the results are actually adopted in practice, but this is dependent on KT activities and other factors beyond CIHR's control.

The indicators in the Health Impacts category will aim to measure the influence of CIHR-funded research in the areas of prevention, diagnosis, treatment and palliation on population health status, PYLL and quality of life. The inclusion of the third health impact indicator suggested in Table 13.2 – the impact of health research on PYLL for target disease categories – is based on more pragmatic considerations. PYLL is part of an ongoing series of health status indicators compiled by Statistics Canada. Approximately 460 000 potential years of life were lost to cancer and 250 000 to circulatory disease in 2001 (Statistics Canada, Cansim Table 102-0311), indicating a large potential for reducing losses through mortality from these conditions.

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In a more advanced evolution of health status measurement, it would be desirable to add a dimension of quality as well as life expectancy – health adjusted life expectancy (HALE) or quality adjusted life years (QALYs), for example.

Reductions in PYLL can be related to advances in knowledge, although there will usually be a margin of uncertainty, especially where there are several contributory factors (*e.g.* prevention, treatment, social determinants). In the case of cardiovascular disease, CIHR is considering a qualitative approach used in the United Kingdom called a witness seminar (UK Evaluation Forum 2006, 19), which brings together a range of experts to identify and discuss the key influences on the development of a particular innovation or research field that contributed to an advance in a health outcome.

13.6.4. Economic impacts

This impact category in the CIHR framework follows a categorization scheme presented by Buxton and his colleagues (2004) in a critical review of the economic benefits of research. Economic impacts are closely related to the concept of return on investment. In the case of funding for health research, however, the emphasis is on social rather than private return on investment.

- The economic benefits of research tend to be diffused throughout society: for example, enhanced earnings and productivity as a result of gains in workforce health.
- In many cases, research produces public goods, which are neither patented nor traded in economic markets. Enhanced understanding of the health benefits of exercise and diet is an example, as are new medical and surgical procedures adopted into publicly financed health-care systems.
- Where discoveries or IP result in patented products or spinoff companies, financial benefits will usually accrue to the researchers who made the discoveries and the institutions that hosted the research (in Canada, usually public universities or hospitals), as well as to the downstream industries that use the products and employees of the spinoff companies. Research funding agencies in Canada receive no direct financial benefit from successful commercialization of IP.

These considerations argue for an approach to measuring economic impacts that is conceptually similar to that recommended for health impacts: measuring the overall economic impacts of research and then demonstrating that a funding agency has contributed effectively by encouraging research.

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In addition, it is important to note that economic impacts can accrue regardless of who the beneficiary is. It is not expected that a public research funder would be the beneficiary of any economic impacts arising from the funded research.

13.6.4.1. Commercialization

Statistics Canada conducts surveys of IP commercialization (Statistics Canada 2005a) and biotechnology (Statistics Canada 2005b). The latter is part of an effort by the Canadian Biotechnology Strategy (CBS) group to develop a set of biotechnology statistics for Canada. CIHR, Statistics Canada and other organizations are partners in the CBS. Statistics produced to date show impressive results in terms of the number of new biotechnology companies and annual earnings, almost half of which is in the health field. Elsewhere in this volume, Rose and McNiven define a series of macroeconomic and microeconomic impact indicators that could be collected in the future.

While at present there are no comprehensive measures of value added from the discovery and adoption of new technology in Canada, ways of measuring this are under consideration (Gault and McDaniel 2005; Earl, Gault and Bordt 2005). CIHR plans to monitor and, when possible, participate in these discussions with the aim of collaborative development of appropriate indicators of commercialization. CIHR also has targeted commercialization programs, such as the Small and Medium-Sized Enterprise (SME) Research Program and Proof of Principle (POP) grants. The SME Research Program is a partnership between CIHR and biotechnology companies that supports university spinoffs and new commercial ventures. The POP program supports university-based researchers in establishing the marketability of an invention or discovery and then moving it towards commercial viability. Follow-up studies of the results of these programs can provide direct measures of commercial results from funding initiatives. For example, since 2001 the POP program has funded more than 160 projects. Of the projects that have matured sufficiently to be evaluated, 63% (49 projects) have resulted in the issuing of new patents, 21% (16 projects) have had IP licensed and 14% (11 projects) have contributed to the formation of a new company.

13.6.4.2. Direct cost savings

The Canadian Agency for Drugs and Technologies in Health (CADTH) provides a national focus for the study of the cost-effectiveness of new technologies and medications. Collaboration with CADTH appears to be a promising approach to defining indicators of cost savings resulting from the adoption of new technologies. Direct cost savings can be realized when

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research findings identify practices (treatments, diagnoses, prevention, organization of care) that are equally or more effective, but less expensive, than current practice; adoption of the new practice would then lead to savings for the system.

13.6.4.3. Human capital

The human capital approach measures the value of potential earnings lost through ill health or injury. Health Canada has published estimates of the burden of disease in Canada using a human capital approach (Moore *et al*. 1997). Work to update the estimates is currently being undertaken by Health Canada, Statistics Canada and the Canadian Institute for Health Information (CIHI). Once the work is complete, it seems feasible that the estimates could be extended to provide measures of the value of illness or injury avoided, or disability periods shortened, as a result of advances made possible by research. For example, where research leads to options for reductions in time to treatment or recovery in areas where burden of disease is also declining, links between the two could be investigated.

13.6.4.4. Potential future indicators

Buxton and his colleagues (2004) described a fourth category of economic impacts: value of life and health. Work in the United States and Australia has sought to measure the benefit of medical advances in terms of the value of life or potential contributions to gross domestic product (GDP) (Murphy and Topel 2003; Nordhaus 2003, 29, 30). The group of experts that discussed the CIHR impact framework thought that such an undertaking would be beyond the framework's scope. The group pointed out that, from a conceptual point of view, GDP is affected by many factors, and there is a well-established system in place to classify and measure the economic determinants of GDP growth. The contributions of indirect factors, such as a healthy population, are not measured in current accounting systems.

13.7. Methodological considerations

The experts involved in the creation of the impact framework identified a number of methodological considerations for the development of a suitable and usable framework and indicators.

- New methods for measuring impacts should build on existing performance measurements and evaluation.
- A variety of approaches and measures is required to cover the scope of CIHR's mandate and research themes.

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- Methodologies should consider and account for the short- and long-term impacts of research.
- Where appropriate, methodologies should permit distinction between the impact categories, specifically those of Health and Economic Impacts.

In addition to these methodological considerations, the group raised two main points with respect to the characteristics of indicators: indicators should be designed so that they can be updated regularly and input from other research funding agencies should be sought; and the involvement of both domestic and international stakeholders is desirable in order to maximize insight, achieve efficiencies by pooling efforts and allow for comparative analysis.

13.8. Challenges

Participants in the framework development process viewed the following as the main challenges in identifying the impacts of health research.

- Linkages between health research inputs, outputs and impacts are difficult to trace when knowledge develops incrementally over time and through multiple channels.
- Health research impacts are often subjective and difficult to measure (*e.g.* improved health can be measured by quality-of-life instruments, but ratings tend to vary depending on context and personal expectations (Carr, Gibson and Robinson 2001)).
- Attribution of credit for research impacts can be complex, as impacts often result from a number of research projects carried out or funded either collaboratively or independently in the same and/or different countries. In addition, the application of research findings is subject to a variety of contextual factors.
- Priorities differ across stakeholder groups. For example, commercial returns are important to industry and government, but may play a subordinate role in the value systems of researchers and the public.

These challenges are interrelated. For example, if linkages between inputs, outputs and impacts were clear, there would be little or no problem in assigning attribution.

One way to try to manage the issue of attribution is to consider impacts at different "orders of effect" (first-order, second-order and so on). The "order of effect" or causality approach recognizes that only some impacts

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are within the direct control of initial inputs (lower-order impacts); other, more distal impacts (higher-order), although not within direct control, will be influenced by initial inputs.

For a research funding agency such as CIHR, "first-order impacts" would include research findings (discoveries/breakthroughs) produced as a result of funding, "second-order impacts" would include commercialization of research discoveries or research findings translated into effective knowledge applications, and "third-order impacts" would include broader health or economic impacts arising from the use of the applications.

This provides a rationale to seek attribution for lower-order impacts and not to focus on attribution for higher-order impacts, but to attempt to measure the latter and understand how they have occurred. For example, in the Health Impacts category, impacts on both life expectancy and quality of life through advances in health research depend on a chain of events or circumstances in a six-step process: *a)* development of new knowledge (discovery) about how to treat an illness; *b)* development of optimal treatment guidelines (knowledge application); *c)* training of professionals in the use of the new treatment; *d)* health providers' decision to adopt the new treatment or follow the treatment guidelines; *e)* access to the equipment, supplies, services and infrastructure required to deliver the new treatment; and *f)* patient acceptance of the new treatment. The latter steps of this process involve KT (the process by which research findings are transformed from a scientific discovery (new treatment) into a clinical application (a practice guideline) that is widely adopted/applied in practice).

The six-step process illustrates two key points for understanding the impacts of health research: *a)* the mere existence of new knowledge will not, by itself, have widespread impacts on health; and *b)* research is pervasive – it plays a key role in each step of the process that links discovery to gains in health status.

In these circumstances, many actors will wish to claim some credit for success. However, an attempt to assign credit to any agent, or even to any one step in the process, seems inappropriate, since no single link in the chain would, by itself, be sufficient to bring about the end result. The process is typically complex, involving multiple funders, multiple institutions and long timelines.

In view of these issues, it may be impractical to attribute credit for the impacts of higher-order effects. Instead, the focus should be on health status gains and their causes rather than on specific contributions. There is a growing awareness that those responsible for research and KT should "celebrate" success rather than attempt to apportion credit for it (Weiss 1977).

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13.9. Conclusion

It is feasible to develop indicators to measure the impacts of health research and health research funding. A conceptual framework is important for identifying the stakeholders who desire or require impact information and for understanding the nature of evidence that will be appropriate for each stakeholder group.

This framework facilitates the identification of areas where specific initiatives can be evaluated to identify impacts, and areas where a more nuanced approach is required. In broad areas, particularly those of health and economic impacts, the most promising approach to impact measurement is to measure the value to society of scientific discoveries in prevention, diagnosis or treatment. Funding agencies, such as CIHR, can demonstrate that they have played an integral part in the success by assuming a leadership role in encouraging appropriate research, by recognizing the potential of discovery in its early stages, by promoting KT, and by undertaking and encouraging the ongoing assessment of impacts.

National and international collaboration between agencies and organizations that have a stake in health research and national statistical and evaluation agencies is the most promising route to the continued development of a robust and credible set of indicators.

This chapter has emphasized the complex challenges that exist in devising credible approaches to the measurement of impacts. This complexity means that no single approach will satisfy all stakeholders or be sufficient to cover all the activities of an agency with a broad mandate, such as CIHR. Nevertheless, as a publicly funded organization, CIHR has an obvious and clear responsibility to demonstrate evidence of both performance and impact.

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Chapter 14

SCIENCE, TECHNOLOGY AND INNOVATION FOR SUSTAINABLE DEVELOPMENT: TOWARDS A CONCEPTUAL STATISTICAL FRAMEWORK

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14.1. The purpose of this chapter

Current science, technology and innovation (STI) conceptual frameworks and classification systems cannot always track the fluid and multiple demands of the policy process, public opinion and current events. Therefore, it is necessary *a)* to build tools that help us to gain insights into emerging topics using existing data and classifications; and *b)* to reflect recurring needs in the revision of current concepts and classifications.

The purpose of this chapter is to consider sustainable development (SD) as an example of the "intent" of STI. "Intent" here overlaps somewhat with socio-economic objective, but it could also include emerging environmental technologies or other crosscutting concepts not yet taken into account in the frameworks and classification systems.

Better linkages between STI and SD will *a)* provide insights into the influence of STI on SD; *b)* allow policy makers to gauge the relative efforts across various social, economic and environmental issues more effectively; and *c)* encourage both STI and SD statistical systems to become more flexible and attentive to changing demands.

Annex 4 of the *Frascati Manual* (OECD 2002a) already provides some advice on "special topics," such as health, information and communication technologies (ICTs) and biotechnology, as crosscutting issues that cannot easily be analyzed with the current classification systems. This chapter suggests a parallel discussion for SD and recommends some feasible approaches.

The chapter reviews the STI classification systems, some existing survey approaches to obtaining information on SD, and the international arrangements for integrating STI and SD indicator development.

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14.2. SD as a statistical concept

Since the Earth Summit in Rio de Janeiro in 1992 (UN 1992), the term "sustainable development" has taken on a multitude of meanings. The UN Millennium Declaration (UN 2000) adopted a broad definition that included sustainable social, cultural, political, economic and environmental development. This has resulted in the Millennium Goals. While their objectives as "foundations of a more peaceful, prosperous and just world" based on "the principles of human dignity, equality and equity at the global level" are admirable, they are not based on a systematic conceptual framework that accounts for the functional relationships between its various components. For example: What is the optimal amount of development assistance? How does deviation from the optimum detract from sustainability?

Environmental economists and statisticians often prefer a more systematic approach. It is possible to incorporate many ideals of SD in the rather anthropocentric concept of sustainable *economic* development, the first principle being that it is possible to encourage "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987).

The framework adopted for this chapter focuses on the natural environment as a source of services required for maintaining and improving human welfare. Keeping the first principle in mind, consideration for future generations dictates the optimal use of these resources by making sustainable use of renewable resources, avoiding the depletion of non-renewable resources and minimizing waste. Statistics Canada experts have proposed a natural capital framework (Smith, Simard and Sharpe 2001), which views natural resource stocks, land and environmental systems (ecosystems) as necessary raw materials that need to be maintained for economic production. From this point of view, SD could be seen as a means of optimizing the interaction between nature and society.

A discussion of STI for (and by) developing countries is included here since their economic development is often more closely tied to SD than that of industrialized countries. In many developing countries, the majority of the population is simply trying to survive. Better agricultural and health practices contribute to major gains in survival. Education provides the basic opportunity for citizens to participate in economic development. Many international development efforts focus on poverty reduction since, in many areas of the world, the immediate need for survival often implies exploiting the natural resource base unsustainably.

The main goal for economic development in developing countries is to use natural and human resources as a means of leverage to improve welfare.

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The degree to which this is done sustainably will determine whether the development succeeds to the point where the country becomes less dependent on its natural resources and can generate wealth from its produced capital and human resources.

14.3. How is SD represented in current STI classification systems?

The degree to which a concept can be represented in classification systems determines the degree to which that concept can be easily analyzed, monitored and reported. Biotechnology, for example, is a technology activity (not an industry), but it is now possible to identify companies, research and development (R&D) activities, products and patents that are related to biotechnology. The ICT sector is also well defined as a set of existing industrial categories (OECD 2002b). Developing international definitions of biotechnology and the ICT sector has required years of international co-operation, deliberations and compromises in revising concepts and classifications. SD is neither a technology activity nor a clear-cut set of industries. It is probably best thought of as an objective. Much as with health, it should be possible to measure whether sustainability is closer to or further away from being achieved, but perfect sustainability may never be attained. However, SD can be associated with certain socio-economic objectives (SEOs), technologies, industries, goods and services, occupations and fields of science.

14.3.1. SEOs

According to the *Frascati Manual* (OECD 2002a, 87), “Performer-based reporting of the socio-economic objectives of R&D is most easily applied in the government and private non-profit sectors . . . although individual countries have applied it in the higher education sector and even in the business enterprise sector” (see Table 14.1).

The difficulty in applying SEOs for R&D in the private sector is that the main objective of most of this R&D is to ensure the long-term profitability of the enterprise by developing and marketing new products (goods or services). It is not a simple task to determine the use to which a given product is put, but it could be done if activities were associated with specific products or broken down by project. Australia is the only country that asks its business sector to identify the SEOs of its research (Australian Bureau of Statistics 2002).

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Table 14.1. Socio-economic objectives of R&D

1. Exploration and exploitation of the Earth.
2. Infrastructure and general planning of land use.
3. Control and care of the environment.
4. Protection and improvement of human health.
5. Production, distribution and rational utilisation of energy.
6. Agricultural production and technology.
7. Industrial production and technology.
8. Social structures and relationships.
9. Exploration and exploitation of space.
10. Non-oriented research.
11. Other civil research.
12. Defence.

Source: OECD (2002a).

Control and care of the environment is included as one of the 12 SEOs in the *Frascati Manual* and is defined as "research into the control of pollution, aimed at the identification and analysis of the sources of pollution and their causes, and all pollutants, including their dispersal in the environment and the effects on man, species (fauna, flora, micro-organisms) and the biosphere. Development of monitoring facilities for the measurement of all kinds of pollution is included. The same is valid for the elimination and prevention of all forms of pollution in all types of environment" (OECD 2002a, 145).

SD is a much broader concept than control of pollution. Some issues relevant to sustainability are addressed under the fifth SEO in the *Frascati Manual* ("Production, distribution and rational utilisation of energy"), but in general the SEO would require modifications and more detail to represent SD appropriately.

The European Union (EU) uses the Nomenclature for the Analysis and Comparison of Science Budgets and Programs (NABS) (EC 2004) to provide a more detailed and comprehensive set of components of "Control and care of the environment" (NABS code 03):

0300 General research on the environment
0301 Protection of atmosphere and climate
0302 Protection of ambient air
0303 Solid waste
0304 Protection of ambient water
0305 Protection of soil and groundwater
0306 Abatement of noise and vibration
0307 Protection of species and habitats
0308 Protection against natural hazards
0309 Protection against radioactive radiation
0310 Other research on the environment

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The Australian Standard Research Classification (ASRC) allows "R&D data to be classified according to the researcher's perceived purpose" (Australian Bureau of Statistics 1998). About 97 of the 594 classes in the ASRC are dedicated to the environment. Other aspects of SD are woven into the remaining classes. The ASRC could provide a useful starting point for a detailed international standard research classification that encompasses SD.

Examples of what is not explicitly included in any of the SEO classifications but that would benefit the elucidation of R&D conducted for the "intent" of SD are:

- R&D for developing countries (specific technologies, health solutions, sustainable agricultural practices, etc.);
- R&D in developing countries (poverty reduction, sustainable use of resources, development planning, etc.);
- Valuation of resources (environmental economics, development economics);
- Resource dynamics (forest regeneration rates, fish stock dynamics); and
- SD as a firm strategy and embedded in standards (such as pollution, energy and waste reduction, corporate social responsibility, adoption of ISO 14000 environmental management standards).

14.3.2. Industrial classifications

There are at least three ways to identify non-standard industry groupings in STI statistics:

- *Existing industrial categories.* The ICT sector is defined as a set of existing industrial categories (OECD 2002b).
- *Technologies used or developed.* Biotechnology companies in Canada are identified by their use or development of specific technologies. All firms within target industry sectors are asked if they use or develop these technologies. Those that do are asked to answer more detailed questions (Statistics Canada 2007).
- *Goods and services produced.* According to Statistics Canada, "the environment industry is composed of establishments operating in a variety of industries that produce environmental goods and services." The latter are goods and services "that are used, or can potentially be used, to measure, prevent, limit or correct environmental damage (both natural or by human activity) to water, air, soil as well as problems related to waste, noise and ecosystems. They also include clean or resource-efficient ('eco-efficient') technologies that decrease material

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inputs, reduce energy consumption, recover valuable by-products, reduce emissions and/or minimise waste disposal problems" (Statistics Canada 2002).

The North American Industry Classification System (NAICS) 2002 (Statistics Canada 2003) includes many industry groupings at the five- and six-digit levels that are related to SD (*e.g.* "54162 Environmental consulting services").

The third revision of the International Standard Industrial Classification of All Economic Activities (ISIC Rev. 3) limits the classification to four digits, so the detailed industry groupings found in the NAICS 2002 are subsumed in broader categories (*e.g.* "K7421 Architectural and engineering activities and related technical consultancy").

Both industrial classification systems would require substantial refinement and additional detail to reflect SD-related industries accurately.

14.3.3. Field of science and technology classifications

Field of science and technology (FOS) classifications provide a means of classifying activities by "communities of practice" rather than by objectives or by the industry of the activities. They are usually more appropriate for classifying activities in higher education since, in practice, activities in government and industry require varying combinations of sciences and technologies to achieve their objectives.

The FOS classification in the 2002 version of the *Frascati Manual* was revised in 2006, and this revision makes the classification somewhat more useful in differentiating some aspects of SD. For example, the social aspects of "1.5 Earth and related environmental sciences" are included in "5.7 Social and economic geography." Given the breadth of the examples under 5.7 ("Environmental sciences (social aspects); Cultural and economic geography; Urban studies (Planning and development); Transport planning and social aspects of transport"), the title might be restrictive.

The detail added to "2. Engineering and technology" allows the classification of environmental engineering (2.7) and environmental biotechnology (2.8).

For the purposes of tracking R&D in and by developing countries, the science of "development economics" might be better emphasized as a sub-field of economics.

As with the SEOs, highlighting SD at a higher level would improve the classification's ability to be used to differentiate SD-related fields.

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14.3.4. Occupational classifications

It would be useful to know *who* is working on SD-related activities. Occupational classifications can give some insight into this.

The International Standard Classification of Occupations (ISCO) is managed by the International Labour Organization (ILO). Although environmental activities and skills are mentioned explicitly in the detailed examples of the current version (ILO 1988), there are no specific "sustainable development occupations". For example, the tasks of civil engineers (2142) include "establishing control systems to ensure efficient functioning of structures as well as safety and environmental protection."

The Canadian National Occupational Classification – Statistics (NOC-S) 2001 (Statistics Canada 2001) similarly includes many SD-related sample job titles within a broader category. For instance, "E031 Natural and Applied Science Policy Researchers, Consultants and Program Officers" includes several examples of job titles, such as "environmental impact analyst", "environmental program co-ordinator" and "environmental program manager". "Development economist" is mentioned in the NOC-S as an example under "E032 Economists and Economic Policy Researchers and Analysts."

Despite the relevant examples, it would be impossible, with either classification system, to discern, for instance, the number of researchers specializing in R&D on SD. As with the industrial classifications, a special survey would be required, perhaps sampling within those classes that include an environmental or other SD component.

14.3.5. Commodity classifications

Sometimes, the best way to distinguish SD-related industrial activities is to focus on the technology used or the product being produced.

Most countries apply a classification of products (or commodities or goods and services) that is based on that maintained by the World Customs Organization (WCO 1988): the Harmonized Commodity Description and Coding System (HS). The HS includes over 5 000 commodity groups, and these tend to cover many of the products of concern in the analysis of SD.

Statistics Canada's Standard Classification of Goods (SCG) is an extension of the HS. The SCG adds two digits to provide more detail for goods that are manufactured in Canada and for those that are imported. In several cases, the additional digits allow the classification of the use of the product.

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Table 14.2. Environmental goods and services listed in the Canadian Environment Industry Survey

Environmental goods

- Air pollution control systems or equipment
- Water supply and conservation systems or equipment
- Wastewater management and sewage treatment systems or equipment
- Hazardous and non-hazardous waste management systems or equipment
- Systems or equipment for remediation/treatment of soil, surface water, seawater and groundwater
- Noise/vibration abatement systems or equipment
- Environmental monitoring, analysis and assessment systems or equipment
- Solar energy systems or equipment
- Waste-to-energy systems or equipment
- Wind energy systems or equipment
- Small, mini and micro hydro systems or equipment
- Fuel cells (transportation and stationary source)
- Alternative fuel technologies (other than fuel cells)
- Cogeneration
- Equipment for methane capture and use from landfill sites or agricultural sources
- Clean technologies and related components
- Other renewable energy systems or equipment
- Any other system or equipment for energy conservation and efficiency
- Other

Environmental services

- Air pollution control services and monitoring
- Water supply and conservation services
- Wastewater management and sewage treatment services
- Hazardous and non-hazardous waste management services
- Services for remediation/treatment of soil, surface water, seawater and groundwater
- Noise/vibration abatement services
- Environmental research and development services
- Energy efficiency and renewable energy services
- Environmental education, training and information
- Management consulting and legal services (including environmental impact assessments)
- Environmental management systems (EMS)
- Other consulting engineering, analytical services, data collection and analysis
- Other

Environment-related construction

Activities for the construction and installation of facilities for:

- Air pollution control
- Water supply and conservation
- Wastewater management and sewage treatment
- Hazardous and non-hazardous waste management
- Remediation/Treatment of soil, surface water, seawater and groundwater
- Noise/vibration abatement
- Renewable energy production facilities
- Other

Source: Statistics Canada (2002).

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The Canadian Environment Industry Survey (Statistics Canada 2002) uses a custom list of goods, services and construction activities that have been designated as "environmental" (Table 14.2). This list was developed in co-operation with clients and respondents, since neither the HS nor the SCG provided sufficient detail to distinguish environmental commodities. The practical outcome of such a broad list of commodities is that a considerable number of companies are included in the definition of the environment industry, as most large firms produce or use some of the more common technologies, such as recycling services.

As with the other classification systems, there are opportunities to refine the categories to make them more conducive to the analysis of SD. One useful approach would be to define a set of emerging environmental technologies and to add these to the "Frascati family" set of statistics (R&D, innovation and human resources). This would allow tracking of the development and use of a specific set of technologies rather than a broad set of industries.

14.3.6. A typology for SD in science and technology

Arundel, Kemp and Parto (2007, 326) propose a typology of six main types of technical environmental innovation that begins to integrate the frameworks of STI and SD:

- 1. *Clean products*. Products designed to have minimal environmental impacts over their lifecycle.
- 2. *Cleaner production*. Process-integrated changes in the production system to reduce the amount of pollutants and waste materials generated during production.
- 3. *Pollution control*. Technology to prevent the direct release of environmentally hazardous emissions into air, surface water or soil.
- 4. *Recycling*. Identifying additional uses for certain production and post-consumer wastes to minimize waste generation.
- 5. *Waste management*. A formal system for handling, treatment and disposal of all waste.
- 6. *Clean-up*. A set of specific technologies to remediate contaminated environmental media (soil, water, air).

This would perhaps be a means of organizing and prioritizing the products and services in Statistics Canada's longer list in a way that is more conducive to the identification of important emerging technologies. An R&D survey, for example, could ask if a company is conducting R&D to

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develop such technologies. An innovation survey could ask if the company has produced new or significantly improved products within this set of technologies.

14.4. Some existing survey approaches that offer insights into SD

Various approaches have been used in national surveys to obtain information on STI related to SD. They all work within the existing STI framework of concepts and classifications.

14.4.1. Specialized R&D surveys

The Canadian R&D surveys (Statistics Canada 2006b) ask respondents the proportion of their R&D dedicated to special areas. The current questionnaire asks for the percentage of R&D expenditures attributable to:

- Biotechnology;
- Prevention, treatment and reuse of pollutants and wastes, and reduction of material and energy use; and
- Advanced materials.

The United States (US Department of Commerce 2005) applies a similar "tagging" approach for biotechnology, software and new materials.

Such "tagging" questions on emerging or crosscutting issues are useful alone or as a means of identifying subpopulations for further inquiry. Used alone, the questions can provide an indication of which sectors engage in R&D in these areas. In Canada, the questions have been used to identify a core group of firms (*e.g.* core biotechnology firms were identified as those with more than 50% of their R&D in biotechnology; see Statistics Canada 2007), the characteristics of which can be further analyzed in terms of sources of funds, human resource allocations, country of control and other factors.

Statistics Canada also conducts a survey on energy R&D (Statistics Canada 2006a). It asks for details about R&D on renewable energy (such as solar, biomass, thermal) and non-renewable energy, energy conservation and transportation. One conclusion from the analyses of the data is that, while expenditures on all energy R&D in Canada increased by 10.5% between the two periods 1994–96 and 2000–2002, R&D in alternative energy grew by almost 50% (Chiru 2005).

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14.4.2. Surveys on public and private R&D intended to support developing countries

In 2004, the prime minister of Canada made a commitment to increase the national effort to "devote no less than 5% of our research and development investment to a knowledge-based approach to develop assistance for less fortunate countries" (Government of Canada 2004). This required a baseline. Canada is well endowed with scientific capital, with almost 112 000 people engaged in R&D in the business enterprise sector and almost 14 000 in the federal government in 2002 (Statistics Canada 2005a). Nevertheless, until recently R&D expenditures devoted to international development by the federal government and the private sector were unknown. In response to these challenges, Statistics Canada, in collaboration with the Office of the National Science Advisor (ONSA), developed two surveys designed to capture that information. The first was a pilot survey to measure the federal government contribution, and the second was a pilot survey to measure the contribution of business enterprises to R&D intended to benefit developing countries.

14.4.2.1. Challenges

The population covered by this project was relatively small. The response rate for the survey of Federal Science Expenditures Intended to Benefit Developing Countries, 2004–2005 (Statistics Canada 2006d) was 90%, and only 13.8% of federal departments declared that they had S&T expenditures for developing countries. The target population for the survey of Research and Development in Canadian Industry Intended to Directly Benefit Developing Countries, 2004 (Statistics Canada 2006e) was 1 249 units. Although the response rate for this survey was 63%, only 2.7% of respondents acknowledged that they had R&D expenditures for developing countries.

The concepts were difficult to define. Respondents commented that they rarely did R&D specifically for developing countries, although developing countries would eventually benefit from the research. There was some confusion between exporting new products to developing countries and performing R&D for their benefit.

The variables measured did not correspond to a specific accounting item. The information captured by these surveys was not standard for accounting items or for other standard classifications. For example, in the accounting books of the business enterprises, there was no specific place to capture the amounts of R&D dedicated to development or economic assistance.

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14.4.2.2. Some results

These surveys provided a first measure of Canada's investment in science intended to benefit developing countries. The federal government had dedicated $151 million in R&D expenditures to benefit developing countries directly. This expenditure corresponded to 2.8% of total federal expenditures on R&D. For the private sector, R&D spending intended for developing countries amounted to 0.4% of total spending on R&D performed in Canada.

Federal R&D expenditures for developing countries were highly concentrated (74%) in public health and agriculture. These two areas are essential to improving basic survival rates. However, they accounted for only about 20% of federal R&D spending overall.

14.4.2.3. Potential ways to improve the surveys

Such surveys in the future would benefit from international standard concepts and classifications, the details of which would have to be developed through a concerted co-operative effort to:

- improve the definitions and concepts (it should be possible to provide explicit definitions and examples of R&D to benefit developing countries);
- identify the specific technologies that Canada develops for the direct benefit of developing countries;
- revise the SEOs in the context of developing countries (*e.g.* poverty reduction, improved water supply, basic health needs, basic education and family planning); and
- develop measures of the impacts of these technologies on developing countries.

14.4.3. Innovation surveys

Canadian innovation surveys already contain special questions to identify industries, technologies and activities. For example, Statistics Canada's Survey of Innovation 2005 (Statistics Canada 2006f) included specific questions on revenues from natural resource products. As with the R&D surveys, this "tagging" approach provides a means of identifying industries, technologies and products. Such an approach could be used to identify other SD-related activities.

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14.4.4. The Bioproducts Development Survey

Recent advances in science and technology (S&T) are creating a new range of products that can be made from biomass resources. These are referred to as bioproducts – that is, commercial or industrial products (other than food, feed and medicines) made with biological or renewable agricultural (plant, animal), marine or forestry materials (Statistics Canada 2006c). Bioproducts development and production form an emerging component of the economy, and their global development can contribute to sustainability and economic growth. For instance, the use of renewable ethanol can reduce dependence on non-renewable petroleum products. Furthermore, bioproducts can contribute to energy conservation by offering alternative ways of manufacturing products, such as the substitution of biodegradable bioplastic bags for plastic bags, thus reducing production costs and damage to the environment.

The world's first Bioproducts Development Survey was conducted in 2003 by Statistics Canada (Statistics Canada 2005b). It had the potential to capture the development and production of these new alternative products by Canadian firms and also to identify indicators that would eventually permit the measurement of the environmental, social and economic benefits of bioproducts development.

Before the conduct of the survey, data on the characteristics of firms engaged in bioproducts-related activities were scarce. As in most emerging sectors, bioproducts firms faced many challenges and barriers, including access to capital and difficulty in attracting highly qualified personnel. The objective of the survey was to gather data on the activities of Canadian firms engaged in the development and production of bioproducts to fill gaps in current understanding of the changes underway in these firms. Specifically, the survey collected information on the firms' use of biomass and other renewable or sustainable biomaterials, the type and number of bioproducts being developed at different stages, the benefits and constraints related to developing bioproducts, human resources devoted to bioproducts, and firms' financial profiles, business practices, access to capital and use of government support programs.

The survey showed that 232 firms were engaged in bioproducts development and production in Canada in 2004 (Boivin 2006). It also demonstrated that, while smaller firms may have been engaged exclusively in bioproducts development, larger firms were involved in it as a complement to their other business activities.

The existence of a bioproducts development sector in Canada itself indicates a shift among business enterprises towards the use of more renewable inputs. Other data, such as R&D expenditures, human resources

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dedicated to bioproducts, and benefits and constraints related to developing bioproducts, are also useful indicators for an understanding of how this set of activities can support SD.

14.5. International institutional arrangements

The collection of environmental statistics has achieved some degree of harmonization at the international level. For example, the United Nations produced a Framework for the Development of Environment Statistics (UN 1984), and these standards have been applied to some degree in national and international collections. However, it is not evident that there is an international consensus on the systematic measurement of the broader concept of SD and its linkage to the economy. According to Gault (2007, 110):

Indicators for "sustainable development" go beyond indicators of "development", and their uses are still evolving. There is no one organization that takes the lead on the production of indicators and guidelines for their development and use and there is a debate on how to approach the question. This debate can be simplified to a question of whether it is preferable to have lists of indicators under descriptive adjectives such as economic, environmental or social, the so called "three pillar" approach, or whether a systems approach is preferable with environmental stocks and flows and the inclusion and measurement of natural capital as a particular stock.

There are likely to be many further opportunities to enhance international co-operation to *a)* improve the acceptance and coherence of SD indicators; and *b)* further the cross-fertilization of STI and SD statistical development activities.

14.6. Recommendations

14.6.1. Improved co-operation

If the STI classification systems and the "Frascati family" of manuals are to be responsive to SD, there will need to be a great deal of co-operation between the international STI and SD statistical communities. This may start as a simple cross-representation in the respective committees of the Organisation for Economic Co-operation and Development (OECD), but eventually international organizations will need to agree on a single set of concepts for SD.

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14.6.2. Improved classifications

This chapter offers some direction for the closer investigation of existing STI classification systems and the initiation of projects to improve the visibility and treatment of SD concepts. This exercise would benefit from the previous recommendation concerning improved international co-operation.

14.6.3. More experience in technology surveys

This chapter focuses on the Canadian experience in survey approaches to obtaining information on SD and other crosscutting and emerging concepts. A project to gather information on other countries' experiences could result in a wealth of existing knowledge. From this, perhaps, international core surveys could be developed. A useful starting point would be to obtain international agreement on a set of emerging environmental technologies, the use and development of which could eventually be tracked through existing STI surveys.

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Part Six

LOOKING FORWARD: WHAT'S NEXT?

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Chapter 15

SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS: THE TWENTY-FIRST CENTURY CHALLENGES

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15.1. Introduction

As the various chapters in this volume illustrate, national statistical offices, in close interaction with the Organisation for Economic Co-operation and Development (OECD), have been particularly influential and constructive over the last 40 years in developing international standards for the measurement of research and development (R&D) and in stimulating and improving the input and output measurement of science, technology and innovation (STI) activities. Behind the early international attempts at coordinating and ultimately harmonizing the measurement of R&D through the establishment of a common statistical manual were two fundamental considerations.

First, there was a growing post-war recognition that most efforts to generate discoveries and inventions had become centred in relatively specialized private and public institutions in the "research and experimental development" network. While there was acknowledgement of the role of a much broader spectrum of scientific and technological services (STS) linked not just to R&D but also to production and other technical activities in both efficient innovation and the diffusion of technical change in many branches of industry, it was the professional R&D laboratory and the activities carried out there that were considered characteristic of the industrial science and technology (S&T) system as it had emerged over the late nineteenth and twentieth centuries.

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Second, in the aftermath of the Second World War, the conviction of the contribution of S&T to military supremacy had gradually expanded to the economic sphere. A nation's industrial strength and competitiveness seemed closely connected to the S&T strengths of the sectors in which OECD countries would specialize. The desire to have better measures for capturing a country's technological competitiveness grew as economic support policies gradually switched from adjustment support for so-called "rust-belt" industries to support for new "sun-belt" high-tech industries. At the same time, as more and more budgetary resources were being allocated to R&D carried out in the public or private sector, it was logical that policy makers as well as researchers would increasingly want the availability of quantitative statistical tools to control the scale of commitment and to learn more about the effectiveness of these activities. It was also quite natural to make comparisons between countries, organizations (public and/or private) and industries as to the direction, scale and efficiency of their national commitments.

On both accounts, as the many chapters in this volume illustrate and as the Blue Sky II Conference in 2006 brought to the forefront, the "context of change," to use Fred Gault's term from Chapter 1, over the last decades has been fundamental. The current twenty-first-century context appears to challenge the statistical STI indicators' focus on the activities of specialized R&D institutions, as well as the particular national location of such activities. As argued in the following section, alongside the process of deindustrialization there has also been a process of "deR&Dization." Other more service-related R&D activities have emerged, sometimes even re-emerged, challenging the relevance of industrial R&D indicators. At the same time and as discussed in Section 15.3, the link between the measurement of national STI activities and their national economic impact, while always subject to debate, particularly within the context of small countries, has now become so loose that national STI indicators are in danger of no longer providing relevant economic policy insights.

Over the last 40 years, the STI indicators community has anticipated the context of change within which STI activities would be carried out. Consider, for example, the expansion of the statistical research interests beyond the concepts and definitions of the old R&D *Frascati Manual* (OECD 1981), and the broadening of coverage beyond the old OECD club of rich countries. The community has been a constant inspiration for policy makers by challenging itself at regular intervals with the statistical tools it has developed and the data it has collected.

Today, the greatest challenge will be for policy makers, still imprisoned by their national sets of democratically chosen rules and regulations, to acknowledge more fully the global public good of STI.

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15.2. The formalization of industrial R&D

Forty years ago, the professional R&D system was barely recognized by economists, despite their acknowledgement that "something" (a "measure of our ignorance," as Mo Abramovitz put it in 1956) was behind most of the economic growth in the twentieth century, and in the post-war period in particular. But, of course, long before the twentieth century, experimental development work on new or improved products and processes was carried out in ordinary workshops.[1] However, what became distinctive about modern, industrial R&D and justified the focus on this concept in the *Frascati Manual* were its scale, its scientific content and the extent of its professional specialization. A much greater part of technological progress appeared attributable to R&D work performed in specialized laboratories or pilot plants by full-time qualified staff. It was this sort of work that needed to be officially recorded in R&D statistics. It was impracticable to measure the part-time and amateur inventive work typical of the nineteenth century. In short, R&D statistics became, and still are, a measure of the professionalization of this activity.

Together with others at the OECD, and in particular Yvan Fabian and Alison Young, one of us happened to be part of the early discussions in the 1960s on the attempt to draw up a formal manual that included or excluded particular activities, culminating in what became known as the *Frascati Manual* (OECD 1976) (see Freeman 1962, 1967, 1969; Fabian 1963; Freeman and Young 1965). It actually appeared particularly difficult to separate research and experimental development activities from the broader spectrum of STS activities concerned with providing support for R&D, disseminating the results, applying new knowledge in various ways, and

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1. As we noted elsewhere: "The classical economists were well aware of the critical role of R&D in economic progress even though they used a different terminology. Adam Smith (1776) observed that improvements in machinery came both from the manufacturers and users of machines and from 'philosophers or men of speculation, whose trade is not to do anything but to observe everything.' Although he had already noted the importance of 'natural philosophers' (the expression 'scientist' only came into use in the nineteenth century), in his day the advance of technology was largely due to the inventiveness of people working directly in the production process or immediately associated with it: 'a great part of the machines made use of in those manufactures in which labour is most subdivided, were originally the inventions of common workmen' (Smith, 1776, p. 8). Technical progress was rapid but the techniques were such that experience and mechanical ingenuity enabled many improvements to be made as a result of direct observation and small-scale experiment. Most of the patents in this period were taken out by 'mechanics' or 'engineers,' who did their own 'development' work alongside production or privately" (Freeman and Soete 1997, 6 and 9). This type of inventive work continues today, and it is essential to remember that it is difficult to capture it in official R&D statistics.

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producing and selling new products. Not surprisingly, organizations that were engaged in research and experimental development were often engaged in such STS activities as well. The *Frascati Manual* tried to distinguish between research and experimental development and related scientific activities. The latter included the following: general scientific library, information and documentation services; training and education of research workers in specialized educational institutions such as universities; general-purpose data collection – for example, routine geological and geophysical survey work, mapping and exploration activities, routine oceanographic survey work, daily meteorological records, monthly production statistics, collection and arrangement of specimens for museums, zoological and botanical gardens; routine testing and standardization activities; and design and engineering activities.

The main theoretical criterion for the Frascati scheme of separation of the R&D function from related scientific activities was the distinction between "novelty" and "routine":

> In so far as the activity follows an established routine pattern it is not R&D. In so far as it departs from routine and breaks new ground, it qualifies as R&D. Thus, for example, the collection of daily routine statistics on temperature or atmospheric pressure is not R&D, but the investigation of new methods of measuring temperature or the investigation of temperatures under circumstances in which they have never been previously recorded (for example, outer space or the interior of the earth) *is* research. Likewise, the publication of a book which simply records daily information on the temperature or pressure is not R&D, but general purpose data collection. The systematic analysis of these recordings with a view to explaining long-term changes in climate, or the possible effects of changes in ocean currents, *is* research activity. To take another example: in the field of medicine, routine general autopsy on the causes of death is *not* research, but special investigation of a particular mortality in order to establish the side effects of certain forms of cancer treatments *is* research. Routine tests on patients, carried out for doctors, as for example, blood tests and bacteriological tests, are *not* research. But a special programme of blood tests in connection with the introduction of a new drug *is* research. (OECD 1963, 16)

On the basis of this criterion, most of the activities of central government testing and standardization institutes, major scientific libraries and information services, museums, and geological and meteorological survey organizations were excluded from research and experimental development as routine-related scientific activities. Also excluded were many scientific and technical activities at the enterprise level, including consultancy, project

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feasibility studies, much design and engineering, production engineering and quality control, as well as training and information services.

Viewed in retrospect, the distinction between novelty and routine seemed relatively straightforward in the early 1960s. Since then, though, new sectors have emerged, such as the software industry, in which this distinction is more difficult to make and is likely to lead to an under-reporting of research in service sectors. As discussed in the following section, this distinction is, however, also important when one considers science-technology systems that are either in a process of rapid growth ("explosion"), such as the emerging economies today, or in a process of rapid contraction ("implosion"). In the case of "exploding" systems, almost all STS would be expanding, but from a statistical perspective there would be an increasing concentration on R&D and hence some reclassification of STS activities in this direction. R&D expenditures would typically increase much more rapidly than R&D personnel in those countries. In the case of "imploding" science-technology systems, a process of involuntary under-development of R&D activities would be set in motion. This was the case after the collapse of the Soviet Union and the end of the centrally planned economies in Eastern Europe. In all those Eastern European countries, there was an abrupt decline in R&D activities in the 1990s, sometimes by more than 50%. However, the fall in expenditure was much greater than the drop in personnel and, according to descriptive accounts, many of those employed in what were once (and sometimes still are) research institutes or R&D departments became engaged in a variety of other STS activities either part- or full-time, such as consultancy, teaching, computer services, information services, design work or production engineering.

Much of the subsequent measurement and indicators research at, for example, the Science Policy Research Unit (SPRU) or at Yale in the 1970s highlighted the fact that the extent of R&D specialization and professionalization should not be exaggerated. Important inventions appeared still to be made by production engineers or private inventors. With every new process, improvements were made by those who actually operated the process. It was also noted that, in many firms, "technical" or "engineering" departments and "operations research" (OR) sections were set up, whose function was to mediate between R&D and production and which often contributed far more to the technical improvements of an existing process than the formal, more narrowly defined R&D department. In retrospect, the focus on R&D seems, however, logical. It was the specialization of the R&D function that justified the use of such expressions as the "research revolution" to describe what happened in twentieth-century industry.

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Industry associations of R&D managers were created in various countries,[2] and most large industrial firms set up their own full-time specialized R&D sections or departments.

To summarize, over the twentieth century formal R&D expenditures rose gradually to become the measure of the technological performance of firms, sectors and countries, even though many other supporting activities fell outside the narrow Frascati R&D definition.

15.3. STI indicators without borders, STI policy makers within borders?

The dissatisfaction with R&D as an "industrial" input indicator was not confined, however, to the omitted role of engineering, design and other STS activities. Following the early SPRU and Yale innovation surveys, it became clear that the actual industrial locus of innovation could well be far upstream or downstream from the firm or sector that carried out the research. Some of our closest colleagues, such as the late Keith Pavitt (1984), Roy Rothwell (1977) and Jo Townsend (1976), had been at pains for many years to stress the much more complex sectoral origin and nature of innovation than the one being assumed through the simple but popular technological classification of industries as high, medium or low R&D-intensive. There is now a large body of literature on the weaknesses and biases of sectoral classifications for STI indicators.

Central in this debate is the extent to which the commercial benefits of knowledge investments can be appropriated and by whom: the firm within the sector having made the R&D efforts, or a firm upstream or downstream, or even the final consumer, imitation taking place so quickly that none of the new product rents could be appropriated by the innovator? Thus, it might well be that sectors and activities with little registered R&D effort are highly innovative. Some of the most competitive British and Dutch industries, such as the offshore and dredge, food processing, finance and insurance industries, carry out little or no R&D. According to OECD classifications, these are typically medium- to low-technology industries. The knowledge bases appropriate to these industries display, however, great technical depth and variety. The list of institutions providing support for and development of these different knowledge bases is quite long and diverse. A low-R&D industry may well be a major user of knowledge generated elsewhere. As highlighted by Dominique Foray elsewhere in this volume, this holds true for many service sectors, where the introduction of new processes or organizational structures, as well as new product innovations, is unlikely to

2. In Europe, the European Industrial Research Management Association (EIRMA) was established in 1966 (*www.eirma.org*).

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involve much formal R&D investment. Here, too, the crucial question will be the extent to which such innovations can be easily imitated, or can be formally protected through patents, trademarks, copyrights or other forms of intellectual property, or can be kept secret.

The same argument holds at the international level. Again, the central question will be whether the commercial benefits of knowledge investments can be appropriated domestically or will "leak" to other countries. In the literature on economic growth, the phenomenon of catching-up growth is typically characterized by lagging countries benefiting from the import of technology and knowledge, both formally and, particularly, informally. In the current context of an increasingly global economy, increasing R&D investment is hence unlikely to benefit only the domestic economy. This holds a fortiori for small economies, which means the vast majority of OECD countries. While there had been some long-standing evidence of a close link between sectoral R&D intensity and export performance and specialization (see, among others, Freeman, Young and Fuller 1963; Freeman 1965; Pavitt and Soete 1980; Soete 1981; and Dosi, Pavitt and Soete 1990), the link between national R&D expenditures and a country's macroeconomic growth, and productivity growth performance in particular, appeared much more difficult to establish (Soete and Turner 1984). It became a central question for the OECD-initiated Technology/Economy Programme (TEP) in the late 1980s.

The TEP was instrumental in bringing together three strands of economic thought. The first was the more institutional and structural change insights on innovation and R&D associated with, among others, Dick Nelson and Sid Winter (1982). The second was some of our own research at SPRU and that of our colleagues Keith Pavitt and Giovanni Dosi on the more formal economic insights from what came to be called at that time "new" growth theory (very much identified with Paul Romer (1986)). The third was the rapidly growing econometric and input-output research on R&D led by the NBER group of Zvi Griliches. This laid the basis for the recognition of the importance of size for technology-based competitiveness, on the supply and on the demand side. A country had to be large or open to have access to knowledge and the specialized labour force required for STI activities, as well as access to a large pool of customers. Increasing national R&D investment without paying attention to the simple observation that "size matters" would either just lead to raising wages for the specialized pool of STI workers – so-called "scientists and engineers" – or would result in the absence of domestic absorptive capacity, with the outcome that such additional R&D investments would leak away abroad.

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The inner logic of these relatively simple and established insights has as yet not fully permeated through to the national STI policy world. Within the EU context, Fred Gault, in Chapter 1 of this volume, notes that the original statement of the Barcelona target of 3% of gross domestic product (GDP) includes innovation expenditures as well as expenditures on R&D. However, it does not take account of possible shortages of available scientists and engineers and the consequences of the likely external leakage effects. Thus, as Meister and Verspagen (2004) calculated, achieving the 3% Barcelona STI target in the European Union by 2010 will ultimately not reduce the income gap between the European Union and the United States, the benefits of the increased R&D efforts accruing first and foremost in the United States and the rest of the world. In a similar vein, Griffith, Harrison and Van Reenen (2004) illustrated in their econometric R&D study how the US R&D boom of the 1990s had major benefits for the UK economy, and in particular for UK firms that had shifted their R&D to the United States. For example, a UK firm shifting 10% of its R&D activity to the United States from the United Kingdom while keeping its overall R&D expenditures at the same level would witness an additional increase in productivity of about 3%, an effect that appeared to be of the same order of magnitude "as that of a doubling in its R&D stock" (Griffith, Harrison and Van Reenen 2004, 25).

In short, the link between the location of "national" firms' private R&D activities and the country's productivity gains appears increasingly loose – for small *and* large countries. For most countries in the world, with the United States as possibly the only exception, the contribution of domestic R&D to the global stock of knowledge is relatively small, and the contribution to domestic productivity growth equally small. There is little doubt that the largest part of worldwide productivity growth over the last 10 years has been associated with an acceleration in the diffusion of technological change and with global access to codified knowledge. The role of information and communication technologies (ICTs) has been instrumental here.

Within the specific European context, the "internal" European market dimension of the international leakage of R&D brings to the forefront the need for a continuous reassessment of domestic European R&D policies, certainly when viewed from the perspective of policies aimed at improving public–private partnerships in R&D. Characteristic of public research is, to some extent, its national embeddedness.[3] Over the last 10 years, several

3. In parenthesis, it can be noted that, based on this perspective, the concept of "*national* systems of innovation" was developed by authors of innovation literature such as Freeman (1987), Lundvall (1992) and Nelson (1993): differences between countries in the set-up and nature of *national* institutions, in particular university education and the public research infrastructure, seem to be able to explain to a large extent differences between countries in innovation strength.

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countries have pursued policies towards increasing domestic "competition" between universities and public research centres. However, this has *not* led to international specialization of public research, but rather to further research duplication. At the same time, the increased international location of private R&D has undermined the close domestic connections between private and local public research institutions. Such opposing trends in, on the one hand, private research dominated by internationalization, specialization and outsourcing and, on the other, public research dominated by nationalization and duplication lead ultimately to increasingly weak links between public and private R&D and a further accentuation of the so-called European "research paradox" (Soete 2006, 214).

15.4. Conclusion

In short, from the perspective of the location of R&D, the twenty-first-century STI indicators debate raises crucial questions about the relevance of domestic R&D policy strategies. These policies will have to put more emphasis on the public–private matching of international R&D specialization patterns with proven international excellence in research than on the competitiveness of national R&D policies between countries and regions.

While there is likely to remain a huge worldwide concentration of research investments in a relatively small number of rich countries/regions such as those of the OECD, with the addition of China, India and Russia, it is important to realize that such activities, whether privately or publicly funded, are becoming increasingly global in focus. The shifts in global demand underlying the process of globalization taking place today also increasingly affect the allocation of private resources to the sort of research, knowledge creation, knowledge diffusion and innovation being carried out in research laboratories, wherever they are located.

Contrary to national *policy* belief, private firms are interested in increasing R&D expenditures not just for the sake of it, but because they expect new production technology concepts and new market-responsive products to improve their own efficiency or strengthen their global competitiveness. Given the much higher risks involved in developing such new products for global markets, firms today often prefer to license such technologies or to outsource the riskiest parts to small high-tech companies that operate at arm's-length but that, once successful, can be taken over. Not surprisingly, in most OECD countries, the large R&D-intensive firms appear less interested in increasing their R&D investments at home than in rationalizing them or, where possible, reducing the risks involved in carrying out R&D by collaboration with others, sometimes through publicly

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sponsored or enabled programs or through so-called “open innovation” collaboration (Chesbrough 2003).

It is here, we would claim, that the broadening of the R&D concept to include “innovation,” with its much stronger local links with growth and development dynamics, is particularly relevant and contains significant new policy insights. From a global growth and development perspective, it is no longer the impact of the transfer of industrial technologies on economic development that should be at the centre of the debate, but rather the broader organizational, economic and social embedding of such technologies in a development environment and the way in which they unleash or block specific development and growth opportunities.

This process is much more complex in the context of a developing country than in that of a developed one. As has become recognized in the endogenous growth literature,[4] the innovation policy challenge with its characteristic “Schumpeter Mark 1” features (entrepreneurial dynamism and “creative destruction”) versus “Schumpeter Mark 2” features (large dominant firms extracting innovation monopoly rents) appears closely associated with levels of development.

In the high-income, developed country context, the innovation policy challenge seems increasingly directed towards questions about the sustainability of processes of creative destruction within environments that give premiums to insiders, to security and risk aversion, and to the maintenance of income and wealth. While the Schumpeter Mark 1 dynamism is needed more than ever for advanced countries to grow along the technological frontier, in the European case it is being undermined by the dominance of Schumpeter Mark 2 features of innovation: large incumbent firms searching for secure innovation rents and the maintenance of their international competitiveness. Innovation policies in Europe have failed to provide sufficient incentives for a Schumpeter Mark 1 innovation process to emerge (Soete 2006). The United States, in contrast, has been more successful, as witnessed by the Small Business Innovation Research (SBIR) program, the lower cost of patenting for small firms, and the rules for public procurement that favour small and medium-sized firms.

4. This view of the philosophy and aims of innovation policies as differing among countries according to their level of development, reminiscent of many of the old infant industry-type arguments, has now become popular in the endogenous growth literature; see Aghion and Durlauf (2005).

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In the emerging developing country context, the challenge appears directed towards the establishment of industrial technological competitiveness through more traditional industrial S&T policies, including support for engineering and design skills and for accumulating "experience" in particular. The BRICs (Brazil, Russia, India and China) provide a good illustration of the innovation policy challenge in the case of emerging developing countries: how to enable "infant" firms from rapidly growing economies to become world players, capable of competing technologically with the multinational corporations (MNCs) of the most advanced countries. The easiest way for such firms to do this is probably to buy up firms from developed countries in order to acquire directly, and build up much more quickly, technological expertise and world-class engineering and design skills. This approach has been observed both in the extraction industries, such as oil and gas exploration, sometimes for political reasons, and in manufacturing, from steelmaking, chemicals and automobile manufacture to some of the newer, high-tech sectors such as electronics, computer manufacture and pharmaceuticals. In the case of emerging economies, waiting for a Schumpeter Mark 1 regime to appear and ultimately to produce firms capable of competing globally in a Mark 2 environment is a risky and slow innovation policy strategy. A strategy of "backing" existing winners seems more appropriate.

The growth trajectory set in motion in emerging economies is to a large extent relatively predictable and straightforward. It is based on the catching-up of their domestic market consumption patterns and productivity levels to those of the worldwide technological frontier, as well as on worldwide specialization based on the gaining of absolute and comparative advantage. Their formal adherence to the World Trade Organization (WTO) has been crucial here. The technology, design and marketing skills needed to sell goods and services internationally that satisfy the quality and delivery criteria of advanced countries will often still be lacking. For the large new MNCs of emerging economies, these skills can best be acquired by the takeover of firms from advanced countries. The innovation policy challenge is, in other words, to create, as quickly as possible, a functioning Schumpeter Mark 2 regime that translates the growth benefits associated with knowledge accumulation and learning into more and better jobs and, ultimately, development. Creative destruction is not an innovation policy priority here.

Finally, there are developing countries, the majority of which are characterized by "disarticulated" knowledge systems, well described by many development economists in the area of S&T (for example, Bell 1994; Sagasti 2004), and where the endogenous innovation policy challenge is of a completely different nature. At first sight, the S&T environment here is not unlike that of Europe in the Middle Ages, where new knowledge remained

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isolated in pockets with no diffusion to the rest of society. The policy challenge here is probably the most difficult of all and is at the centre of a revival of research on S&T and innovation and development that falls somewhat outside the scope of this book.[5]

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5. For an elaboration, see Soete (2007).

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Chapter 16

LOOKING AHEAD: WHAT IMPLICATIONS FOR STI INDICATORS DEVELOPMENT?[1]

Alessandra Colecchia
OECD

16.1. Introduction

The OECD has worked for 50 years to develop indicators and policy analysis of science, technology and innovation (STI). In 1957, an *ad hoc* group of experts met to discuss methodological problems of surveys of research and experimental development expenditure. In 1961 the OECD was formed and the Directorate for Scientific Affairs held a conference in 1962 to systematically address the problems of measuring R&D – the first "blue sky" STI indicators conference dedicated to developing new indicators to serve STI policy formulation. In some ways, these early pioneers were too successful. Of all the STI indicators, R&D and constructed indicators such as the R&D intensity of a country (R&D/GDP), are by far the most popular and have now been enshrined in specific STI policies as quantifiable targets. This interest persists, notwithstanding the fact that the weaknesses of this indicator are well-known, most notably that it measures only one type of STI input (R&D) within a complex system of different innovation inputs and outputs.

In the mid-1990s, OECD Science Ministers requested that the organization launch a "New S&T Indicators" project. Dubbed the "blue sky indicators" project, its objective was to think creatively, without limiting horizons, about developing new indicators to serve policy needs. Ministers asked member countries *"…to collaborate to develop a new generation of indicators which can measure innovative performance and other related output of the knowledge-based economy."* The challenge was to propose new indicators that would shed light on the broader system of innovation,

1. This chapter draws on Arundel, Colecchia and Wyckoff (2006), Colecchia (2006), Gault (2007) and a summary of the Blue Sky Forum prepared by Anthony Arundel for OECD Committees.

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including outputs. In 1996, the first 'dedicated' Blue Sky conference took place, ten years later, the Blue Sky II Forum in Ottawa (September 25-27, 2006) reviewed progress to date in the development of STI indicators and searched for new ideas.

In between the two Blue Sky events, as Fred Gault writes in Chapter 1, the nature of science, technology and innovation has changed, and so has the need for indicators to capture these processes and the interplay between them. This volume brings together some of the ideas that emerged at the Blue Sky II Forum in Ottawa. New measurement challenges at the interface between science systems, industrial innovation, human resources, and knowledge flows were discussed, as well as the inadequacy of existing statistical measures for analyzing those linkages and the dynamics of science, technology and innovation in an increasingly globalized world.

Rather than breaking new ground on indicators, most of the discussion at the Forum reflected a need to fill in major gaps in indicator coverage as part of the current STI measurement research agenda. There is, however, new emphasis on using indicators to tell compelling stories, to emphasize outputs and impacts, to make micro data and linked data sets more accessible, and to increase the policy relevance of the work. This concluding chapter offers some thoughts on Blue Sky II and its key messages to the STI community and puts them in the context of a future OECD agenda for STI indicators.

16.2. Innovation in the *broad* sense

Unsurprisingly, most of the contributions and discussion at Blue Sky II were about innovation, rather than science and technology. This is a welcome development that should help to clarify the use of the term *innovation*. Richard Hawkings, for example, notes that invention and innovation are distinct processes. He writes, in Chapter 10, that "most of the indicators in current use (particularly patents, R&D and publications data) are oriented, in effect, towards invention" and are not measures of innovation. He further notes that "inventions and innovation are different (even if related) and, in many cases, the analytical parameters of innovation may not be related to technology at all." In current practice, the term 'innovation activities' can describe *the broad process*, encompassing science (the basis for some but not all inventive activity), the diffusion and commercialization of product and process innovations, and the implementation of non-technological innovations in marketing and organizational practices. Both of the latter are now part of the *Oslo Manual* on innovation (OECD/Eurostat 2005). Tara Vinordrai, Meric Gertler and Ray Lambert in Chapter 5 discuss industrial design as an example of one form of non-technological innovation.

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A broad view of innovation can be divided into two main targets for measurement: invention-based innovation and diffusion-based innovation. Invention-based innovation can be generated in university or industry labs or be directly driven by users. In all cases, it is about actors and their interactions. These can be users and their interactions (von Hippel, Chapter 8); firms and their heterogeneous business practices and choices of innovation paths (Fabling, Chapter 9); universities and the multiplicity of their knowledge transfers pathways (Hawkins, Chapter 10); or, students and researchers exchanging knowledge across sectors and borders (Auriol, Chapter 11). Given the role played by interactions, it is not a surprise that many of the gaps that have been identified have to do with measuring *linkages*.

Inventions, as with technology, can also be adopted and modified to generate diffusion-based innovation, a concept policy makers are increasingly interested in, as pointed out by Anthony Arundel in Chapter 4. Information and communication technologies (ICT) have been widely used to support the diffusion of knowledge by openly distributing innovation processes across actors and sectors of the economy. Such general purpose technologies can also be seen as part of the broader innovation process, playing a large role in making innovation an increasingly collective endeavor in the global market, and in diffusing it within and across markets.

Scientific and non scientific knowledge, as well as general purpose technologies, can all be viewed as contributing to the broader concept of innovation. In this context, it would be of added value to focus on the measurement and analysis of issues at the interface between science, technology and innovation. This could require trying to answer several basic questions: the extent to which science and technology contribute to innovation performance; the ways scientific and technological advances are brought to the market and are diffused and used; where and by whom the returns from investing in this knowledge are appropriated; and, what, in contrast, are the characteristics and contribution of non scientific and non technological knowledge to innovation.

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The focus on innovation and the need for evidence-based analysis in this area is echoed in current OECD policy discussions An OECD Innovation Strategy, along the lines of the OECD Jobs Strategy (OECD 1996), is currently being developed. The goals of the Innovation Strategy are to develop evidence-based analysis and benchmarking, a framework for dialogue and review, new indicators on the innovation-economic performance link, initiatives for innovation-friendly business environments, and the development of best practices and policy recommendations.[2]

16.3. Blue Sky messages to the STI community

The Blue Sky II appraisal of the current supply of innovation indicators, in the broad sense, is a critical one. With the exception of several under-exploited indicators obtained from innovation surveys, the available range of indicators is almost entirely limited to inputs, innovative activities, and intermediate indicators that measure *invention*, or the *disclosure* component of the innovation process, such as patents and bibliometrics. This seems to be the result of a fragmented effort in indicators development, possibly due to the lack of a comprehensive framework to guide measurement research in this field and to an ongoing focus on R&D. In the words of John Marburger (Chapter 2), "we have a lot of data, some correlations, but no models" in the STI area. Moreover, sometimes the available data are based on remote proxies rather than direct measurement and thus the results are inadequate (Foray, Chapter 6). These scattered efforts prevent a full understanding of how innovative activities lead to social and economic impacts, which is a necessary prerequisite to the development of appropriate and coherent policies. Understanding the full story of innovation, and being able to tell it, requires a lot more than data on R&D or on other innovation inputs. The Blue Sky Forum identified the need to develop additional indicators for short term outcomes and the longer term impacts of innovation, as well as a comprehensive analysis of the effect of innovation on outputs and impacts.

2. See the Chair's Summary of the OECD Ministerial meeting on 15-16 May 2007: *www.oecd.org/document/22/0,2340,en_2649_201185_38604566_1_1_1_1,00.html*

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The need for indicators of activities, linkages, outcomes and impacts is hardly a radical departure from existing thought. However, developing a framework for the measurement of innovation in the broad sense is not straightforward. At the macro-level the growth accounting framework could be used to approximate the impact of innovation related investment, and this would be part of the broader effort and challenge encountered in measuring intangible assets in an economy.[3] Also at the macro-level, modeling innovation inputs and outputs as part of a production function, or as a "knowledge" function as referred to in the literature, can be done and has been done at different levels of sophistication. Private and social returns can be estimated, although the analysis has often been restrained by data availability. In the past, R&D spending has been used as the input and patent counts, or dichotomous variables such as weather or not a firm has innovated, have proxied innovation outputs. Participants in the Forum argued strongly for going beyond this limited view.

The lack of direct measurement can certainly be compensated with econometric techniques that can account for missing variables; however, this does not shed much light on the debate around the role of government in innovation policy and productivity growth (Fabling, Chapter 9). Moreover, the macro-level framework is unable to explain the heterogeneity of actors' innovation paths or their dynamics and interrelations.

A recurring theme of the Blue Sky Forum was the importance that firm-level analysis, both cross-sectional and longitudinal, can have in informing policy makers on the nature of the innovation process and its impacts on productivity. Unfortunately, limitations on access to micro data and data linkage problems reduce the number of experts than can analyze data and the range of research questions that can be explored, especially in an internationally comparable way. Both create major barriers to the construction of a full range of STI indicators and to analytical research on the outputs and impacts of innovation. This work also requires agreement, acceptable to the international community, on concepts and definitions for both the measurement and interpretation of the data.

3. One component of innovation expenditure, expenditure on research and development (R&D) according to the *Frascati Manual* definition, has recently been recognized as a capital investment in the system of national accounts. At the OECD, NESTI is working jointly with national accountants on methodological issues raised by the accounting of R&D in the SNA framework, such as: coverage and valuation of R&D production, estimation at constant prices and international prices, R&D imports/exports, constructing R&D stocks, and overlap between R&D and software. Guidelines for the capitalisation of R&D in the System of National Accounts will be part of the forthcoming OECD Handbook on Intellectual Property.

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Solutions to problems of data access and database linkages need to be found in order to provide better information to the policy community. The ability to link different data sets, at both the micro and macro levels, can improve understanding and reduce respondent burden. For example, the ability to link innovation survey data to business practice surveys or to administrative databases on firm level capital investment, earnings, value added and employment can substantially improve econometric research on the effects of innovation on economic outcomes and reduce respondent burden by not having to replicate questions in the innovation survey.

Participants in the Blue Sky II Forum were challenged to make STI indicators, and their policy applications, as well known, and as relevant, as those of the System of National Accounts (SNA). Another recurring theme at the Forum was the need to improve the relevance of indicators to policy, as well as increase the input of the policy community into the design of STI indicators. The Forum supported more research into developing a science of science policy, which will require going beyond work already being done by existing science policy research groups around the world. As part of this project, the growing interest in public accountability creates a demand for indicators to support the evaluation of public spending programs and of public institutions.

To summarize, four key messages were sent from Blue Sky participants to the wider STI community.

1. Research on innovation in the *broad* sense is currently fragmented. There is a need for a **general framework** of analysis and greater **coordination of research efforts**. The goal is to understand the entire story of innovation, from inputs to economic and social impacts.

2. Indicator and related econometric research must move forward from innovation inputs and activities to include the **outputs and impacts** of innovation.

3. New methods of analysis are necessary to understand innovation processes, which will require **improved data access**, **data linkages** and the adoption of **interdisciplinary approaches** to data.

4. A marked improvement in the **policy relevance** of innovation research is required in order to create a science of science policy.

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16.4. What implications for OECD work on STI indicators?

All four messages from the Forum participants are interlinked. Improved access to data is required to develop new indicators and to conduct analyses that can improve understanding of impacts. Better data access can involve micro data, linking different data sets, and adopting a more interdisciplinary approach to innovation research. The OECD plays a central role in each of these four areas: coordinating the development of new and improved indicators; coordinating new research to evaluate the outputs and impacts of innovation; promoting solutions to data access; and, supporting research of high policy relevance.

The development of STI indicators at the OECD has been guided by the Working Party of National Experts on Science and Technology indicators (NESTI). While the core competences of NESTI are the development of statistics and methodological guidelines on R&D, Innovation and Human Resources in Science Technology (HRST), its activities have expanded in this last half a century to directly oversee work on biotechnology statistics, patents and bibliometrics, R&D tax incentives, and technological balance of payments. The latest addition is forthcoming work on the measurement of nanotechnology, while work on indicators for the information society was spun off into an ad hoc group that has subsequently become the Working Party on Indicators for the Information Society (see Gault, Chapter 1).

While STI indicators work at the OECD is mainly under the responsibility of one group, a lesson learned in these last years is that STI indicators are not the sole province of those working in the STI area. OECD work on information society statistics, on multinational enterprises (MNEs) statistics, entrepreneurship statistics, productivity statistics, education and migration statistics, taxation statistics and national accounts, are all fundamental to advancing the measurement and understanding of science, technology and innovation issues. The point is that the need for coordination of research efforts goes far beyond research *by* and *for* the STI community. One result is that NESTI has increasingly sought to collaborate and build synergies with different OECD groups, with other international organizations, and with non-OECD economies.[4]

4. The OECD Main Science and Technology Indicators (MSTI) (OECD, 2007) publishes data for nine non-OECD economies (Argentina, China, Israel, Romania, the Russian Federation, Singapore, Slovenia, South Africa and Chinese Taipei). Brazil, Chile, China, Israel, South Africa, UIS (the UNESCO Institute for Statistics) and ESTAT (the Statistical Office of the European Commission) are official observers to NESTI activities; also, RYCIT (the Ibero-American network of Science and Technology indicators) regularly participates. For the first time in 2007, NEPAD (the New Partnership for Africa's

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To what extent does NESTI's current and future program of work address the Blue Sky II call for measures of outputs and impacts? To some extent it already does. Work on R&D capitalization in national accounts will allow estimation of the macroeconomic impacts of investment in R&D. Work on collecting direct measures of indirect support to R&D (a measure excluded in the *Frascati Manual* (OECD 2002:142) is ongoing and will allow better evaluation of the impact of public support to R&D. An effort to develop indicators of commercialization of public and private research is just starting. A research proposal to revise measurement guidelines in the HRST area and analyze the role HRST play in innovation and economic performance has been prepared in anticipation of resources being made available.

Perhaps the best example of a current project to better exploit the potential of existing innovation survey data is the NESTI-WPIA Innovation micro data project.[5] The project addresses the determinants and impacts of innovation at the firm level across countries. Its added value is its international scope: indicators and econometric estimates based on the same methodological approach are applied to national data sets in a large number of countries. Experts from over 20 countries are involved in the project, including several non-OECD economies (Brazil, Chile, the Russian Federation and Slovenia).[6]

Development) participated in the NESTI meeting, seeking ways to collaborate on STI indicators development. Additional non-OECD countries, such as India, participate in specific NESTI activities, notably the projects on the careers and mobility of doctorate holders (CDH project).

5. This OECD project was launched as a joint endeavor of NESTI and WPIA (The Working Parting on Industrial Analysis, previously called SWIC) in May 2006.

6. The indicators themes include: standard innovation indicators, innovation modes and performance (*i.e.* composite indicators reflecting the degree and type of innovation performed by firms), innovation linkages (with universities, between companies etc.), and obstacles to innovation. The themes selected for econometric analysis (which will also entail the compilation of comparable indicators) include: *i)* innovation and productivity; *ii)* channels of international technology transfer; *iii)* non-technological innovation; and *iv)* intellectual property rights (IPRs). Important characteristics of the firm will be taken into account in those analyses, including its size, the industry it belongs to and its multinational character (or not).

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The project overcomes data access limitations by running national econometric models on innovation survey micro data in parallel, rather than seeking to combine national micro data into one large data set. The national teams of experts run similar statistical operations on their respective national data sets: data cleaning; compilation of indicators, and econometric regressions. The core data come from innovation surveys such as the fourth European Community Innovation Survey, coordinated by Eurostat, or similar innovation surveys from countries outside of Europe. The innovation survey data are linked with data from other national surveys and/or business registers in order to improve the sophistication and accuracy of the econometric models.

This decentralized approach, with each national team working on its own data set, is required by the confidential character of survey micro data. That legal constraint explains the fact that, apart from a few exceptions, there is almost no recent multi-country analyses using innovation survey micro data.[7]

The project must overcome two major obstacles: imperfect comparability of innovation survey data (especially for non European countries), and differences across participating countries in the ability to link innovation data at the firm level to data from other surveys. The latter is necessary for many economic analyses that require company balance sheet data. One of the objectives of the project is to demonstrate the potential of linking surveys, registers and other administrative sources to analyze innovation impacts. One of the results is likely to be a strong message for granting greater data access to micro data for analytical and policy relevant purposes.

The fourth key message of the Blue Sky II Forum is to improve the policy relevance of STI indicators and analysis. This requires the direct input of the policy community. One option is to apply ‘user driven innovation’ in the development of indicators, for example by creating systems that permit policy users to continuously influence and contribute to indicator design. Another option is to map user needs with available indicators and identify data gaps and priorities for new indicators. Either or both methods would supplement the current influence of academics and national statistical offices on indicator development.

7. The situation should improve in the future, with micro data for several EU countries now available for researchers at the Eurostat safe centre in Luxembourg. However, the Eurostat micro data are limited to questions included in the CIS, with no possibility to link the CIS data to other survey results.

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Both methods are currently used at the OECD in the development of STI indicators. NESTI itself regularly evaluates the strengths and weaknesses of the indicators it develops and works to improve their quality by strengthening and revising its methodological guidelines. It has dealt with the issue of policy relevance and multidisciplinarity by increasing collaboration with policy groups inside and outside the OECD and by organizing conferences such as the Blue Sky series. On the other end, policy makers have the opportunity to feed directly into NESTI's work by providing guidance and appraisal through its parent committee, the Committee for Scientific and Technological Policy (CSTP), and its subsidiary bodies. Furthermore, NESTI has been dealing with the increasing complexity of the subject area by leveraging the skills and good will of active member countries. Groups on specific issues, from informal groups such as task forces and expert groups, to more formal arrangements such as ad hoc meetings, have multiplied.

While the OECD has implemented many different methods for improving the policy relevance of STI indicators and analysis, there is still substantial room for improvement. However, the current context of limited budgets for statistical agencies results in fewer resources to experiment, to develop new indicators, to launch new surveys, or even to add new questions to existing surveys. One solution is to adopt a flexible approach to statistical micro data that permits greater exploitation of existing data. An example is the use of different aggregations, in addition to sector or firm size, to help respond to policy questions, rather than being constrained by standard classification systems. This is partly a data access issue, as discussed above.

16.5. Conclusions and challenges ahead

Since the first Blue Sky meeting in 1996 the nature of OECD work on STI indicators has changed considerably. The scope has broadened with the increase in the number of areas and issues covered. The focus has changed from mainly statistical and classification issues to increasingly analytical research and work that is more directly linked to policy. And, the breadth of activities has expanded from measuring R&D to measuring innovation in a broad sense. This has included the development of statistical frameworks for emerging interdisciplinary technologies (first ICT, followed by biotechnology, and nanotechnology in the near future), to new approaches to the measurement of HRST, and to new techniques of analysis based on micro data.

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While science and technology, especially new information technologies, were a key determinant of growth performance across countries in the 1990s, with the advent of the new millennium broader trends have become apparent that create a new context for STI indicators. In particular, new measurement challenges come from changes due to globalization and the environment, including the demand for and supply of natural resources.

R&D provides a good example of the challenges of globalization. Following the broader fragmentation of the value chain and the corresponding internationalization of manufacturing, new trends are emerging in how R&D is performed.[8] In some sectors, such as pharmaceuticals, the trend is towards a decline in the dominance of large multinational firms in R&D expenditures, with increasing shares of R&D performed by small and medium sized firms. Another trend is towards the outsourcing of R&D to "R&D services" firms, many of which, while classified in services, undertake R&D for manufacturing industries. New ways of conducting R&D are also emerging, such as using joint ventures and alliances and outsourcing R&D to foreign affiliates. Yet, the current structure of data collection is tied to models of national R&D performance that are increasingly unrepresentative of how and where R&D is performed by firms (National Research Council, 2005). Christopher Freeman and Luc Soete in Chapter 15 analyze extensively the changing nature of R&D and its increasingly globalized nature. Other contributions to the Blue Sky II forum have tackled the very difficult issue of measuring the internationalization of R&D.[9] This complex measurement agenda is currently on the OECD work program and it is likely to remain there for the years to come.

More generally, the location where the value of research and innovation is created and captured is changing. Firms are increasingly relying on external sources of knowledge rather than in-house expertise. Research (including public research) is increasingly commercialized via spin-off companies and in some sectors the licensing of patented technologies (OECD 2004) plays a growing role in knowledge transfer In this context it becomes difficult to obtain measures of the value of innovation and to answer questions about who is appropriating the returns from innovation. Finally, while increasingly relying on networks of actors across geographical locations, science and innovation activities also tend to cluster in particular locations or around certain institutions (*e.g.* a leading university or a

8. The internationalisation of R&D is not a totally new phenomenon, since some R&D has been undertaken abroad for a long time. However, cross-border R&D has traditionally been the corollary of foreign direct investment and until recently largely aimed at adapting technologies for sales in host countries. (OECD 2006a).

9. See the contributions of Åkerblom (2006) and Perani and Cozza (2006).

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research laboratory of a multinational corporation). Geographical boundaries and traditional units of analysis, such as the nation, might not be the best choice for analyzing the changing landscape in science, technology and innovation.

Another challenge comes from major technological shifts, with a new shift possibly underway due to a rapid increase in the demand for energy. While worries about limits to oil supplies have existed for some time, the growing demand from China and India coupled with continued instability in the Middle East brings these concerns to the foreground. Perhaps, more significant is the better understanding of how the consumption of carbon-based fuels is changing the climate. Both trends are open to debate, but when the two trends are combined, it becomes clear that science and technology will have to address the need for a conversion from fossil fuels to other sources of energy and/or methods such as carbon sequestration to minimize the release of carbon dioxide into the atmosphere. These large, long-term trends underscore the need for a more forward-looking approach to STI indicators that can meet policy requirements over the short and medium-term future. Michael Bordt, Julio Rosa and Johanne Boivin (Chapter 14) provide examples of existing classifications that can be used, or questions that have been or can be added to existing surveys, to measure issues related to "sustainable development". For example, R&D and innovation surveys have been used to measure scientific and innovation activity for specific types of technologies, such as the group of related technologies that make up biotechnology. The same approach could be used for other sets of technologies, such as environmental technologies to look at issues of "eco-innovation".

In the shorter term, the challenge is to render statistical systems more flexible and responsive to the introduction of new and fast evolving concepts that are typical of the science, technology and innovation field. There are several ways of doing so, for example experimenting with satellite accounts, adding questions to several surveys, or adding topic-specific modules to main survey vehicles every *n* years. Experimental and flexible approaches could progress at different speeds according to countries' specific priorities and resources. This will require some coordination to prevent geographically fragmented research efforts over the long-term and ensure that the results of successful experimentation in a limited number of countries are taken up by the international community.

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In the longer term, a challenge for the statistical community is to redesign surveys to address the relevant unit of STI analysis. Should data be collected at the level of research laboratories to address questions about basic research? Is the group level a more relevant unit of analysis than the enterprise level when looking at R&D? Should innovation surveys use the establishment to look at the diffusion of new process technologies? Another challenge is to restructure data collection in a way that maximizes data linking opportunities for research and the analysis of impacts. This also means finding ways of providing researchers with access to micro data while at the same time meeting confidentiality concerns.

In a context of limited budgets for statistical agencies, there is a crucial need to obtain the full support of the policy community by providing them with useful indicators and analyses. One goal is for the international STI policy community to develop a "science" of STI policy based on empirical STI data and indicators, similar to the reliance current Ministers of Finance and of the Economy place on economic metrics. A second goal is to ensure that the Ministers of Finance and of the Economy recognize STI policies as central to the promotion of economic growth and sustainable development. Both goals require more resources to be committed to developing improved STI indicators and analysis as part of an overall measurement strategy. The OECD is in the process of developing an innovation strategy, to be informed by policy relevant indicators and empirical analysis. This is a window of opportunity for mobilizing policy support and resources that is not to be missed.

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Abbreviations

Advanced manufacturing technology (AMT)

Australian and New Zealand Standard Industrial Classification (ANZSIC)

Australian Productivity Commission (APC)

Australian Standard Research Classification (ASRC)

Association of Universities and Colleges of Canada (AUCC)

Business expenditure on R&D (BERD)

British Medical Journal (BMJ)

Business Operations Survey (BOS)

Business Practices Survey (BPS)

Brazil, Russia, India and China (BRICs)

Computer-aided design (CAD)

Canadian Agency for Drugs and Technologies in Health (CADTH)

Canadian Biotechnology Strategy (CBS)

Careers of doctorate holders (CDH)

Collège du Management de la technologie (CDM)

Commission of the European Communities (CEC)

Centre for Economic Policy Research (CEPR)

Canadian Institute for Health Information (CIHI)

Canadian Institutes of Health Research (CIHR)

Competitiveness and Innovation Framework Program (CIP)

Community Innovation Survey (CIS)

Canadian Internet Use Survey (CIUS)

Canada Research Chair (CRC)

Crown Research Institutes (CRIs)

Centre for Research on Innovation and Competition (CRIC)

Canadian Science and Innovation Indicators Consortium (CSIIC)

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Centre for the Study of Living Standards (CSLS)

Department of Trade and Industry (DTI)

Design Industry Advisory Committee (DIAC)

European Commission (EC)

European Community (EC)

European Commission Bureau of European Policy Advisers (EC-BEPA)

European Industrial Research Management Association (EIRMA)

European Knowledge Area (EKA)

Environmental management systems (EMS)

European Parliament (EP)

European Patent Office (EPO)

European Research Area (ERA)

European Space Agency (ESA)

Economic and Social Commission for Western Asia (ESCWA)

European Statistical System (ESS)

European Union (EU)

Foreign Affiliates Trade Statistics (FATS)

Food and Drug Administration (FDA)

Foreign direct investment (FDI)

Field of science and technology (FOS)

Full-time equivalent (FTE)

Government budget appropriations or outlays for R&D (GBOARD)

Gross domestic product (GDP)

Gross domestic expenditure on R&D (GERD)

Government expenditure on R&D (GOVERD)

Health adjusted life expectancy (HALE)

Higher education R&D (HERD)

Health Economics Research Group (HERG)

Household Internet Use Survey (HIUS)

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Her Majesty's Stationery Office (HMSO)

Human resource management (HRM)

Human resources for science and technology (HRST)

Harmonized Commodity Description and Coding System (HS)

International Adult Literacy and Life Skills Survey (IALS)

Improved Business Understanding via Longitudinal Database Development (IBULDD)

Information and communication technology (ICT)

Information and communication technologies (ICTs)

Indicators of education systems (INES)

Information technology (IT)

Intellectual property (IP)

Initial public offering (IPO)

Intellectual property rights (IPRs)

Forschungsinstitut zur Zukunft Arbeit (Institute for the Study of Labour) (IZA)

International Labour Organization (ILO)

International Patent Classification (IPC)

International Standard Classification of Education (ISCED)

International Standard Classification of Occupations (ISCO)

International Standard Industrial Classification of All Economic Activities (ISIC)

International Organization for Standardization (ISO)

Knowledge Economy Indicators (KEI)

Knowledge management (KM)

Knowledge translation (KT)

Mergers and acquisitions (M&A)

Manufacturing Advisory Service (MAS)

Ministry of Economic Development (MED)

Multinational corporations (MNCs)

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Nomenclature for the Analysis and Comparison of Science Budgets and Programs (NABS)

Nomenclature statistique des Activités économiques dans la Communauté Européenne/ Classification of Economic Activities in the European Community (NACE)

North American Industry Classification System (NAICS)

National Alliance of Provincial Health Research Organizations (NAPHRO)

National Bureau of Economic Research (NBER)

National Experts on Science and Technology Indicators (NESTI)

Not-for-profit (NFP)

National Occupational Classification – Statistics (NOC-S)

National Science Board (NSB)

National Science Foundation (NSF)

Nomenclature of Territorial Units for Statistics (NUTS)

Outward direct investment (ODI)

Organisation for Economic Co-operation and Development (OECD)

Ordinary least squares (OLS)

Office of the National Science Advisor (ONSA)

Online public access catalogue (OPAC)

Operations research (OR)

Office of Science and Technology (OST)

Private non-profit expenditure on R&D (PNPRD)

Proof of Principle (POP)

Potential years of life lost (PYLL)

Quality adjusted life years (QALYs)

Research and development (R&D)

Research and Development in Canadian Industry (RDCI)

Regional Innovation Scoreboard (RIS)

Rolling mean employment (RME)

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Related scientific activities (RSA)

Research scientists and engineers (RSEs)

Research and technology development (RTD)

Research Unit for Research Utilisation (RURU)

Science and engineering (S&E)

Science and technology (S&T)

Small Business Innovation Research (SBIR)

Standard Classification of Goods (SCG)

Sustainable development (SD)

Survey of Electronic Commerce and Technology (SECT)

Socio-economic objectives (SEOs)

Standard Industrial Classification (SIC)

Science, Innovation and Electronic Information Division (SIEID)

Stanford Institute for Economic Policy Research (SIEPR)

Small and medium-sized enterprises (SMEs)

System of National Accounts (SNA)

Statistics New Zealand (SNZ)

Système d’Observation Permanente sur les Migrations (SOPEMI)

Science Policy Research Unit (SPRU)

Science, technology and innovation (STI)

Scientific and technological services (STS)

Technology/Economy Programme (TEP)

Technology, Organizations and Environment (TOE)

Technology Transfer Office (TTO)

UNESCO Institute for Statistics (UIS)

UK Innovation Survey (UKIS)

United Nations (UN)

United Nations Educational, Scientific and Cultural Organization (UNESCO)

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United Nations University (UNU)

United Nations University-Maastricht Economic Research Institute on Innovation and Technology (UNU-MERIT)

United States Patent and Trademark Office (USPTO)

World Commission on Environment and Development (WCED)

World Customs Organization (WCO)

OECD Working Party on Biotechnology (WPB)

OECD Working Party on Indicators for the Information Society (WPIIS)

World Summit on the Information Society (WSIS)

World Trade Organization (WTO)

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Science, Technology and Innovation Indicators in a Changing World

RESPONDING TO POLICY NEEDS

As part of engaging a wider community of policy users and indicator developers, *Science, Technology and Innovation Indicators in a Changing World: Responding to Policy Needs* is a selection of the papers discussed at the OECD Blue Sky II Forum (Ottawa, 25-27 September 2006). Policy needs, measurement issues, and some of the challenges in describing cross-cutting and emerging topics in science, technology and innovation (STI) are presented; ideas to exploit existing data and develop new frameworks of measurement are shared. The intent of the debate is to guide future development of STI indicators at the OECD and beyond.

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