

Science-Matrix

Final Report

March 2005



Towards a Canadian Biotechnology Innovation Scoreboard

Prepared for the
Industry Canada
Life Science Branch

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Science-Metrix specializes in the measurement and evaluation of science, technology and innovation. Our data collection and assessment methods include bibliometrics, scientometrics, technometrics, surveys and interviews, environmental scans, monitoring and intelligence gathering. We perform program and policy evaluations, benchmarking and sector analyses, market studies and strategic planning. Science-Metrix has a robust knowledge of life and environmental sciences.

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Executive summary

The aim of this study is to provide Industry Canada and the Canadian Biotechnology Secretariat with a skeleton scoreboard for measuring the performance of the Canadian biotechnology sector. This scoreboard uses international benchmarking to identify areas of the sector where Industry Canada can take action to help it grow. Science-Metrix' mandate was to study the constitutive elements of a scoreboard designed to measure innovation performance. This document provides the guidelines and building blocks, including potential indicators, for the building of the scoreboard.

We describe what constitutes a good scoreboard; the qualities needed to make it a useful policy-making tool and insure its continuity. The links with the objectives of Industry Canada are made explicit, particularly in relation to competitiveness, quality of life and sustainability in an analysis of biotechnology in Canada.[To respond to Industry Canada's needs Science-Metrix adopted a three-pronged.] The study consisted of three stages: first, the literature on innovation was reviewed; second, the existing scoreboards on innovation and biotechnology were analyzed; third, based on the first two stages a list of indicators was produced based on practical feasibility and theoretical justification. The study is novel in using current scientific work on innovation to justify the choice of indicators, rather than simply choosing those indicators where data are most readily available.

The review of the literature on innovation provides the theoretical background for the selection of indicators. Two types of literature were consulted. Analytical frameworks such as those developed in *The New Production of Knowledge* and work on national systems of innovation are useful in conducting benchmarking exercises on biotechnology. They help to explain the macro-level dynamics characterizing modern-day science and their relation to the industry, which contributes to producing new or better indicators to account for the biotechnology innovation process. The second type of literature consulted covers analyses of specific elements of the innovation structure that are put in place by governments, industries and even universities. The literature highlights important dimensions of the biotechnology innovation process, for example: the role played by public R&D in economic development, the role of entrepreneurship in feeding the biotechnology industry, and the role of government fiscal incentives in fostering its development.

The existing innovation scoreboards, notably those of the OECD and EC, were consulted. S&T indicators can be generally classified within three sub-classes: 1) patents and scientific publications; 2) personnel in the private and public sectors; 3) private and public investment, financing, and R&D/manufacturing expenditure.

The OECD biotechnology indicators consist of five main types: 1) Publicly funded biotechnology R&D as a percentage of publicly funded R&D; 2) Dedicated biotechnology firms; 3) Patents; 4) Biotechnology venture capital investment; 5) Genetically engineered crops. The data collected by the OECD are very incomplete and are sometimes compiled from heterogeneous sources. This makes it impossible to derive a global estimate of national levels of performance, and affects both sustainability and comparability.

The European Biotechnology Innovation Scoreboard (BIS) is more exhaustive in terms of number of indicators, but it is a one-off effort and therefore is not useful for studying the evolution of the biotechnology industry. The BIS defined more variables than was ultimately practical and feasible to collect. The data were intended to cover: inputs and resources; scientific and technological outputs; collaboration and science and technology transfer; and information on use, outcomes and impacts of biotechnology. However, of the fourteen types of data that it was planned would be collected for the BIS, only nine were effectively available or practical to collect, and not all data were available for all countries. Both the OECD and EC scoreboards are interesting, but have too many shortcomings to be used as models.

After reviewing the innovation literature and analyzing the existing scoreboards, Science-Metrix decided on the following indicators for the construction of the Canadian Biotechnology Scoreboard:

Human resources

- R&D workforce in industry, government and universities;
- Number of employees overall.

Companies

- Number of dedicated biotechnology firm.

Financial variables

- R&D spending in industry, government and universities;
- Venture capital;
- Value of publicly traded biotechnology companies;
- Company revenues;
- Size of the local market, imports and exports.

Scientific and technological outputs

- Number of scientific publications, citations per publication;
- Number of patents granted by the USPTO; applications for patents to the EPO; triadic patent families;
- Collaboration between sectors.

Acronyms

BUDS	Biotechnology use and development survey
CBS	Canadian Biotechnology Strategy
CRO	Contract research organization
DBF	Dedicated biotechnology firm
GDP	Gross domestic product
IP	Intellectual property
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
S&T	Science and technology
SME	Small and medium enterprises
STI	Science, technology and innovation
UN	United Nations
VC	Venture capital
UNIDO	United Nation Industrial Development Organization

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1 Introduction

Innovation scoreboards are particularly popular in Europe, and in international organizations such as the Organisation for Economic Co-operation and Development (OECD) and branches of the United Nations (UN). Statistical scoreboards are not new; they have existed for year the form of statistical yearbooks, statistical compendia, benchmarking studies, and in the guise of indexes such as the Human Development Index. In the field of science and technology (S&T), the US National Science Foundation (NSF) has been publishing Science and Engineering Indicators regularly since 1972. Thus, although scoreboards are not new, more recently the term *scoreboard* has come to be associated with science, technology and innovation (STI) indicators that are updated on a regular basis (e.g. annually, biannually). The objective of such scoreboards is to inform, and to stimulate debate among policy-makers and other stakeholders as exemplified by the following statements:

United Nations Industrial Development Organization (UNIDO) - Industrial Development Report 2002 / 2003¹ - "The principal objective of the UNIDO Scoreboard is to help policy-makers, and business communities and support institutions to assess and benchmark the performance of their national industries and analyze their key drivers".

UK Department of Trade and Industry 2003 R&D Scoreboard² - "The objective of the scoreboard is to encourage more effective investment in R&D as part of the innovation process, by stimulating informed debate within and between companies and their investors on the importance of R&D investment".

The objectives of this study is to examine what are the determinants of innovation and of industry performance in biotechnology (Section 2 and Section 3), to examine how they have been measured in existing biotechnology scoreboards (Section 4) and to propose a scoreboard that meets the needs of the Canadian policy-makers and other stakeholders involved in the biotechnology industry.

Before embarking on a study of what are the determinants and measures of innovation, it is useful to establish the salient features of an innovation scoreboard and the key dimensions that need to be taken into account (Section 2). Importantly, the goals set by the Canadian Biotechnology Strategy (CBS) are not only to increase the performance of the industry in the short run, but also to make it sustainable over the longer run. The latter aspect is rarely taken into account by existing scoreboards.

There is an abundant literature on innovation and its determinants. *Macro level* theories attempt to explain how innovation occurs and to identify the actors, processes and activities involved in innovation, mostly at the *system level*. The innovation literature is also concerned with more micro-level evidence that is often provided by empirical studies examining the *constitutive parts or ingredients* of innovation systems. This literature plays an important role since generally it is these individual

¹ <http://www.unido.org/doc/24397>

² <http://www.ecdti.co.uk/CGIBIN/priamlnk.cgi?MP=CATSER%5EGINT65&CNO=1&CAT='RE01'>

ingredients that are the variables that are measured. The macro and micro level approaches are examined in Section 3.

Section 4 examines current biotechnology scoreboards designed by the European Commission (EC) and by the OECD to illustrate how innovation can be measured in terms of stakeholders' objectives as well as in terms of a coherent framework or one that measures its individual parts. Reviewing the theory and the empirical evidence on innovation is important since existing scoreboards often fall short in terms of explaining the link with existing innovation theory and empirically demonstrated causality. For instance, in its attempt to build a scoreboard on biotechnology, the European Commission (2003a) did not link the indicators used to an innovation model. The rationale is given for each dimension, but the debates and lack of consensus surrounding innovation and its constituents and dimensions are not detailed. Other European Innovation Scoreboard documents suffer from the same problem (European Commission 2003a). In a report for the OECD, Arundel (OECD 2003b) expands on the rationales behind the selection of indicators for a biotechnology scoreboard and to an extent relates these to the literature on innovation. However, the explanations are not linked through any coherent or systematic model or theory.

2 Indicators and the art of scoreboarding

This section is comprised of two parts. Section 2.1 presents key definitions and lists some of the most important aspects of a robust scoreboard. Section 2.2 identifies the main Canadian stakeholders behind the definition of the present scoreboard and derives some of the important aspects that should be measured given their objectives.

2.1 Elements of a robust scoreboard

A scoreboard is an instrument used for monitoring performance and is designed to track and measure representative aspects of a program, agency or system at regular time intervals in order to provide stakeholders with meaningful information. The information contained in a scoreboard is usually grouped in sets of dimensions, which are broken down into a series of indicators. Dimensions are the determinant aspects of a system that need to be appraised. For instance, the quality of the staff is a determinant dimension in the propensity of the health system to deliver high quality health care. Another dimension might be the quality of the equipment. Dimensions are usually measured by a number of indicators. For instance, the quality of staff could be measured by years of experience, educational achievement, vocational training received, etc. while the quality of equipment might be measured by age, whether it allows state-of-the-art, non-intrusive procedures, etc.

Dimensions and indicators should be:

- Relevant and useable;
- Meaningful and understandable;
- Balanced and comprehensive;
- Mutually exclusive and parsimonious;
- Timely, but sustainable and relevant over the long term.

Relevant and useable – A scoreboard should comprise relevant dimensions and indicators, that is, they must be appropriate for the measurement of the system being monitored. Ideally, they should be selected using a top-down approach, that is, first a logic model of the system is drawn and subsequently the relevant dimensions and indicators are selected. Scoreboards are sometimes populated with indicators that are *available* as opposed to those that are *most relevant*. Although it is necessary to be pragmatic in the design of a scoreboard, a bottom-up approach sometimes lead to scoreboards that lack relevance. In addition, scoreboards must be useable. If the indicators are not used by the community, they will not have any effect on what people do.

Meaningful and understandable – Dimensions and indicators need to “speak” to stakeholders, to enable them to understand how the information translates into tangible outcomes. Ideally, the dimensions and indicators should be suggestive of actions that could be taken to tackle particular situations. Dimensions and indicators must be simple, and at the same time they must be meaningful and have as great an explanatory power as is possible.

Balanced and comprehensive - Dimensions and indicators should ideally include all the necessary variables to understand the performance of a system. They should be balanced in the sense that there should not be several indicators covering one aspect of the system, and no indicators for other aspects.

Mutually exclusive and parsimonious – There is little point in providing a scoreboard with multiple overlapping indicators. Such scoreboards are ultimately expensive to build, while overlapping makes mathematical modeling harder and complicates the use of statistical regressions to explain the roles played by the different dimensions. Being parsimonious not only results in greater mathematical robustness, it simultaneously reduces data collection costs and makes the results more transparent for busy, information-overloaded, decision makers. Nevertheless, although the number of primary indicators used in a system must be as small as possible and as mutually exclusive as possible to reduce collection cost and to increase explanatory power and ease of mathematical modeling, it is often useful to have indicators that fan out to increase the subtleties of a system. For example, GDP is a potent indicator in many situations, but it does not give a complete picture of the wealth of a country, which is why analysts often use GDP per capita to obtain another appreciation of wealth. For instance, China is rapidly becoming one of the wealthiest countries overall, but in terms of per capita GDP, it is obvious that in relative terms it lags far behind.

Timely but sustainable, and relevant over the long term – Decision-makers are always demanding information to meet their short term needs. They require information that is up to date. Although it is important for scoreboards to satisfy these requirements, there must be balance with the capacity to provide indicators that will be relevant over the long term – i.e. indicators need to survive the immediate demands of the political world if they are to be instruments useful for the longer timeframe of policy-making in science and technology related fields where discoveries and development typically take decades to reach the marketplace.

2.2 Stakeholders in a Canadian biotechnology industry scoreboard

In creating a scoreboard, one of the main criteria is who will be the stakeholders. We showed in Section 2,1 that one of the first requirements of a good scoreboard is that it must be relevant and useable. Of course, relevance and usability vary greatly depending on who are the stakeholders. Thus, a scoreboard's degree of relevance and usability reflect individual values and occupations.

In the case of the Canadian biotechnology industry scoreboard, the main stakeholder is Industry Canada. The relevance of the indicators is related to the mandate and objectives of this department. Industry Canada's mandate is to help make Canadians more productive and competitive in the knowledge-based economy, which will improve the standard of living and quality of life in Canada. More specifically, Industry Canada's policies, programs and services aim to support the growth of a dynamic and innovative economy to: provide more and better-paid jobs for Canadians; support stronger business growth through continued improvements in productivity and innovation performance; give consumers, businesses and investors confidence that the marketplace is fair, efficient and competitive; and to ensure a more sustainable economic, environmental and social

future for Canadians. Through its three strategic objectives (a fair, efficient and competitive marketplace; an innovative economy; and competitive industry and sustainable communities), Industry Canada aims to help Canadians contribute to the knowledge economy and improve their productivity and innovation performance.³

The scoreboard also needs to reflect the goals and visions of the CBS, which is funding this study. The CBS is aimed at enhancing the quality of life of Canadians in terms of health, safety, the environment and socioeconomic development by positioning Canada as a responsible world leader in biotechnology. The guiding principles of the CBS are to: reflect Canadian values; engage Canadians in open dialogue; promote an innovative economy, sustainable development, competitiveness, public health and scientific excellence; and ensure responsible action and cooperation domestically and internationally. The goals of the CBS reflect the need for Canadians to have access to, confidence in, and benefit from safe and effective biotechnology-based products and services. This is to be achieved largely through an effective scientific base and continuing excellence in Canada's regulatory system (CBAC 2002).

Figure 1 offers a diagrammatic interpretation of these goals and the means of achieving them. There are three main poles that are common to Industry Canada's mandate and to the CBS: the need to increase competitiveness through various measures of economic development; the need to increase quality of life through various measures of social development; and the need to obtain a sustainable system through various measures that touch the development of the social, economic, biotic and abiotic environments.

The easiest aspect of the CBS to measure is competitiveness. There are many dimensions that can be measured in this connection: Industry Canada and CBS documents indicate productivity improvements, company growth, innovation performance, scientific excellence, and investor and business confidence. Improvement in quality of life is somewhat more difficult to measure, and certainly harder to quantify. The most obvious dimensions to measure are number of jobs, and salary and wage levels. However, there are also very important dimensions linked to health and safety. Biotechnology is often seen by scientists and businesses as contributing positively to these aspects, whereas the public tends only to see the potentially adverse effects of biotechnology-related procedures and products. Consumer confidence, which is an aspect mentioned in relation to quality of life, reflects business and investor confidence. The most difficult aspect to measure, and one that seldom appears in innovation scoreboards, is sustainability. In a democratic country, open dialogue is clearly one of the means to facilitate sustainability; similarly, domestic and international cooperation can promote sustainability by balancing short and long term views and creating an environment open to trade and longer term development. The expression "Canadian values" is somewhat ambiguous: it is not explicit, it is fairly heterogeneous, and it is not clear whether and how these values contribute to sustainability or the other poles. For the sake of this exercise, we assume

³ <http://www.ic.gc.ca/cmb/welcomeic.nsf/ICPages/Mandate>

that most Canadians value democracy and an open society, which are likely to be factors contributing to sustainable development.

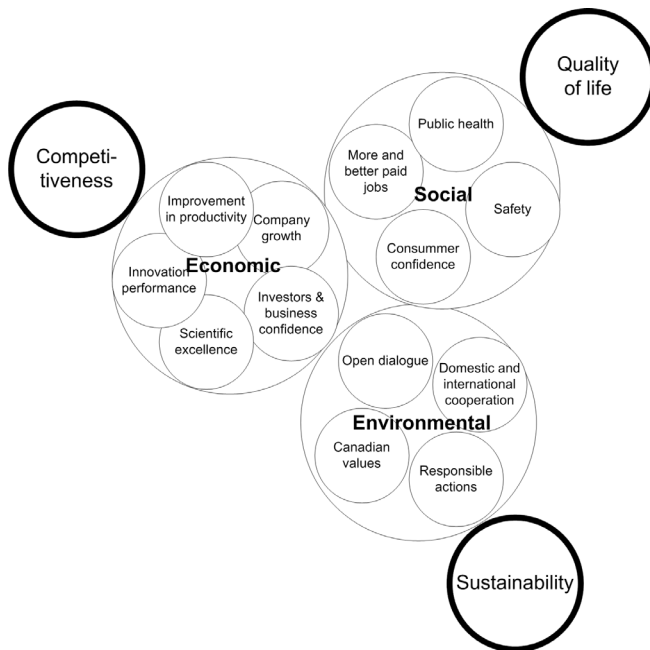


Figure 1 The three poles of biotechnology development in Canada

Source: Science-Metrix from Industry Canada and CBS documents

Looking at the three poles depicted in Figure 1, it is immediately obvious that achieving Industry Canada's and CBS's goals, which are simultaneously complementary and conflicting, is a complex process. For instance, competitiveness and quality of life are sometimes at odds. For firms to be competitive, they have to employ people efficiently and pay them a competitive wage. This is not to say that competitiveness derives from using cheap labour since in many cases an industry needs to employ the best talents available, which often necessitates higher rates of pay for scarce skills. However, it is in the interests of business owners and shareholders that employees' wages should be set at levels that will allow businesses to derive the biggest profits, and produce stock options and rewards for senior management and boards of directors (see, for instance, Galbraith 1967). For the wider public, unemployment is the enemy; more jobs must always be better, and obtaining a higher income is an important ingredient in a better quality of life.

The objectives of Industry Canada and of the CBS sometimes run counter to an increase in productivity. Sustainability runs counter to competitiveness and quality of life in the short term, but helps these factors over the longer term. To be competitive sometimes involves using resources in an irresponsible manner, creating more profits and better paid jobs in the short run, but at the expense of the environment, and the survival of the industry and the firm and, therefore, for employment and the capacity to remunerate workers in the future.

Hence, seeking an optimal level of performance can be considered as a type of "hard combinatorial optimisation problem" (see e.g. Kauffman 1995: 248). Trying to find the optimal level of

performance in such a context invariably brings us back to the problem of the finality of a scoreboard. A scoreboard should be an instrument to study and to understand the level of performance of a system. A well-designed scoreboard can therefore be an extremely useful instrument to demonstrate how increasing one part of a system affects other parts. For instance, we can assume that higher wages increase quality of life, but how do they impact on economic competitiveness? How does increasing consumer confidence affect investor and management confidence and, conversely, how do policies that increase "business" confidence play on consumer confidence? In these complex combinatorial problems, where increasing one component in the system often adversely affects other aspects, it is extremely important to be focused, to ask the difficult questions, and to be able to measure them properly. Hence, the capacity to define an effective scoreboard depends on the presence of an open society and on the capacity to openly discuss controversial issues. The controversy arises in part because of the priorities of the numerous actors and stakeholders that constitute the socio-economic system.

Although the mandate of Industry Canada and the vision of the CBS are fairly extensive, they overlook one important issue. We contend that their *raison d'être* is a recognition that the public's objective is *wealth building*. Here, wealth is not to be construed as only pecuniary accumulation. Wealth should be seen also as the value of knowledge, culture, health and well-being, buildings and other such dispositions and physical assets in the system. Wealth building is the item that has to be maximized at the system level and there are three hard combinations required to achieve this: economic development, social development, and sustainability. Bringing the question of wealth building and wealth creation to the fore forces clear identification of who are the actors in this system. For instance, neither Industry Canada nor the CBS mention the presence of the Canadian State and civil servants as stakeholders and beneficiaries of a well-performing biotechnology industry. Clearly, the State and civil servants have an incentive in having well performing industries: taxes levied on businesses and individuals increase the wealth of the State which allows it to accomplish its mission and to remunerate civil servants. Wealth building is also an objective for citizens who will benefit from the services rendered by the State including better quality health care and a safe living environment with good education opportunities –values that most Canadians cherish. But wealth building is clearly an objective of the more direct stakeholders in the systems, namely the workers, management and directors, and the shareholders. What is significant here is *wealth building* or *wealth creation*. It is important to state that most citizens, which includes those who have selected not to pursue economic wealth since our definition of wealth comprises knowledge, culture and even spirituality, would like to see their wealth increase over time. Sustainability is key to building and to creating as opposed to destroying. In a sustainable system, growth itself is a hard combination that involves setting aside short term benefits to increase the potential for longer term wealth.

A discussion on wealth creation therefore makes explicit who are the actors and how they can benefit from the performance of the system. It identifies some obvious indicators for the biotechnology industry, for example:

- The number of jobs that exists, the wages earned, the number of hours worked per person, and the level of job satisfaction can all be used to measure the wealth of the workers in the system.
- The volume of sales by firms and their profitability, and the revenues earned by managers, directors and shareholders provide an indicator of business wealth creation.
- The amount of income taxes levied on companies, staff and shareholders provides an indicator of wealth building by the State.

These indicators could be used to compare performance levels across countries; they could be used to compare performance in different industries; and they could be used to examine the evolution of performance over time. The first two types of analysis are called stationary distributions since they do not require a time variable, but rather are observed within a set timeframe. For instance, during 2000, how much tax accrued from the biotechnology industry compared to other industries in Canada? During that same year, how did the taxes collected in Canada compare to those collected in other countries? On the other hand, time-series address questions such as how do the taxes collected in the biotechnology industry in 2000 compare to those collected in previous years. Just as the overall goal of the system, which may be said to be wealth building, comprises a static (wealth) and a dynamic (building) variable, a good scoreboard would ideally allow both static and dynamic examination of a system.

3 Theoretical and empirical evidence on innovation performance in biotechnology

The European Commission's survey on innovation (European Commission 2004a) is an attempt to establish a systematic list of the "ingredients" (to use the European Commission's terminology) of an innovation system, with each element being justified by a brief rationale. These ingredients however are not linked in a coherent model which can be tested as a whole. In some documents, statistics are simply presented, with little or no rationale provided for the selection of specific indicators (OECD 2004b). Elements of reflection are often presented concerning the possible improvements to indicators and their ability to represent reality, but these rarely derive from an explicit desire to understand the process of innovation better, and how it can be accounted for empirically through measurement (KPMG 2002; OECD 2001a; OECD 2003c). These studies often fail to explain how a dimension fits into the innovation process and why measuring it might be a good indication of the performance level of a country or how countries will derive socio-economic benefits from it. Thus, rather than using these scoreboards as a starting point, this section examines the theoretical and empirical literature on innovation.

The objective of this section is to examine how current theories (Section 3.1) and empirical evidence (Section 3.2) on innovation may provide useful insights for the construction of an innovation scoreboard in the field of biotechnology. Section 3.1 starts by examining theories on the role played by innovation on economic development at the national level with an emphasis on biotechnology. The evidence reveals that none of the existing models is sufficiently complete and all-encompassing to provide a firm basis for the construction of a scoreboard. However, these models and theories, are useful for identifying some of the constituent dimensions that might form the building blocks for a scoreboard with theoretical foundations.

3.1 Insights from theory

This section examines how current theory can be used to design a new framework that has a sound theoretical foundation. It is important to note that the existing frameworks are not theories per se, in the sense that physicists or chemists would say a coherent set of statements amounts to a theory. The literature reviewed here describes mainly heuristic approaches used to identify the factors and structures that contribute to innovation and how they interact, and as such they can be considered to be analytical frameworks rather than grand theories of innovation with complex sets of rules, laws and hypotheses. These frameworks represent social scientists' attempts to coherently organize very disparate and complex information on how and why innovation contributes to economic and social development. They could therefore be used as a source of inspiration in the building of a rational scoreboard.

3.1.1 Science, innovation and the knowledge economy

Compared to industry activities that are fairly stable, innovative industries encompass the idea of change. Research and development (R&D) is a fundamental ingredient of this capacity to change products and processes, and is itself inspired by the methods developed by scientists. There is a presumption that innovation drives economic growth, that innovation is driven by R&D, and that R&D itself is fed by science (Conceição, Heitor and Veloso 2003; Smith 2002). For example, Carayannis and von Zedtwitz (2005: 95) argue that “There is ample and growing evidence that intangible resources such as knowledge, know-how and social capital will prove to be the coal, oil, and diamonds of the 21st century for developed, developing, and emerging economies alike”.

Despite this optimism, most contemporary theories of innovation reject a linear model in which scientific research leads to discoveries, which themselves lead to products, which are subsequently introduced in the marketplace (Etzkowitz and Leydesdorff 2000; Freeman 2004; Gibbons *et al.* 1994; Lundvall 1998; Lundvall *et al.* 2002). For one thing, several authors have convincingly demonstrated that many scientific questions originate from technical problems (see e.g. Rosenberg 1982). In this context, it is accepted that several frameworks and more or less sophisticated concepts have attempted to explain how science and economic growth interact, for example “the knowledge economy”; “mode 2 production of knowledge” (Gibbons *et al.* 1994); “national systems of innovation” (Freeman 2004; Lundvall 1998; Lundvall *et al.* 2002); “the Triple Helix” (Etzkowitz and Leydesdorff 2000).

The framework elaborated by Gibbons *et al.* (1994) is an attempt to explain how science and innovation participate in the knowledge economy (and also how science works when it does not participate in the knowledge economy). The authors argue that two “modes” of knowledge production coexist, each with its own motives for conducting science and its corresponding evaluation criteria. In Mode 1 science, which is characterized by the advancement of science for its own sake, excellence in research should be judged according to purely internal criteria, that is, based on scientific interest and contribution to the cognitive development of theories. The economic and, to a lesser extent, social returns from science are side effects, rather than ends in themselves. In this respect, the performance of the system would be expressed through the personal drive, creativity and scientific aptitude of the individual researchers composing it, and the capacity of the institutions and cultures to respond to the researchers’ needs.

By contrast, in Mode 2, the economic impacts of science become of prime importance as innovation is linked to national prosperity, personal well-being and industrial competitiveness. Indeed, following Gibbons *et al.* (1994), innovation becomes the prime element responsible for improving a company’s profitability and maintaining the economies of industrialized countries ahead of those of emerging competitors. Furthermore, the public in general, and interest groups more specifically, expect innovation to be a source of social, human and environmental betterment. To the scientific criterion already present in Mode 1, Mode 2 adds external dimensions such as economic and social criteria. Good innovation performance, for the defenders of Mode 2 theory, should produce important economic and social returns. In Mode 2 the various steps of the innovation process are

not associated with a specific institution. Government agencies, universities and firms can all be involved in basic research, development, commercialization and use of an innovation which is economically viable – i.e. which does not lead to losses. Knowledge production is no longer limited to the act of formulating a set of ideas and possibly putting them into practice. Knowledge production also includes the shaping of knowledge to fit a particular situation or use. Its production is thus distributed across networks, which can include a large number of heterogeneous actors who will rearrange the knowledge following certain sets of attitudes and values. These characteristics multiply the number of institutions, actors and also intangible factors to include in the innovation process.

The distinction between Mode 1 and Mode 2 can be seen as a distinction between two competing views of what science should be. Mode 1 is associated with a vision of the university as an “ivory tower” while Mode 2 is associated with the current interest in the knowledge economy where science acts as an engine of economic development and wealth creation.

Biotechnology clearly is closer to Mode 2 knowledge production than Mode 1. The field can therefore be expected to show the specificities described above, among which the presence of a large number of heterogeneous actors is probably the most important. Also, it must be borne in mind that biotechnology is a field where innovation is the main driver of competitiveness. Firms, universities and governments all participate in the creation of a pool of basic and applied knowledge, which aims as much to further our understanding of the world as to contribute to wealth creation through economic competitiveness. Thus, when considering the concept of Mode 2 knowledge production, a well performing national system of biotechnology is one that produces high quality research, but also contributes solutions to both industrial and social issues and seeks to improve the prosperity and well-being of societies in the immediate future as much as in the longer term. This relates especially to biotechnology, a field where substantial investments have been made, and where, to a large extent, results have yet to materialize. Indeed, while there are a number of biotechnology companies, the majority of them have yet to commercialize or participate in the commercialization of a product, and most still rely heavily on venture capital (VC) (for an indication of the fragility of the biotechnology industry in Canada, see BioQuebec 2004).

3.1.2 System level analytical frameworks

While the description of Mode 2 knowledge production provides a general description or overview of how innovation in biotechnology should work, a number of other analytical frameworks can provide more specific information about just who might be involved and how they are involved in such a process. Although such frameworks can by no mean be integrally translated into a logical model with a view to producing a scoreboard, they do provide some elements of reflection which should be taken into account during its construction.

National systems of innovation

One of the most relevant frameworks for the current study is the national systems of innovation framework that was developed by scholars such as Bengt-Åke Lundvall, Christopher Freeman and

Richard Nelson. The framework of the national system of innovation focuses on describing the institutions that form such a system and how their specificities affect system-level performance. Lundvall (1998: 409) argues that:

The focus on interactive learning evokes also the important role of economic structure and institutions in determining the rate and direction of innovative activities. Institutions understood as norms, habits and rules are deeply ingrained in society. They play a major role in determining how people relate to each other, and how they learn and use their knowledge. In an economy characterized by on-going innovation and fundamental uncertainty the institutional setting will determine how the economic agents behave.

Nasierowski and Arcelus (2003: 216, citing Dahlman 1994) argue that national systems of innovations are:

[...] network of agents and set policies and institutions that affect the introduction of technology that is new to the economy. The key aspects of NIS are the extent to which the economy acquires technology from abroad, the intensity of domestic technological effort it undertakes, and the level of technical human capital.

Furman, Porter and Stern (2002) build upon these concepts with their framework called the *national innovative capacity*, which comprises three building blocks:

- A strong common innovation infrastructure (a country's overall S&T policy environment, mechanisms for supporting basic research and higher education, a "stock" of technical knowledge upon which new ideas are developed and commercialized);
- Innovation environments present in a country's industrial clusters;
- Links between the common infrastructure and industrial clusters.

The authors distinguish between scale-based differences (population, GDP, R&D workforce, R&D spending, etc.) and productivity-based differences (intellectual property (IP) protection, international trade, share of academic vs. industry R&D, etc.). The framework is interesting since it aims to measure quantitatively the effects of a number of dimensions on the R&D performance (as measured by patents) of countries, a goal quite similar to the one pursued here. The dimensions measured include number of patents, number of full-time-equivalent scientists and engineers, gross expenditure on R&D (performed in university and in industry) and size of the population as a measure of the number of potential workers available for innovative activities. Furman, Porter and Stern also include some measures of policy choices, such as the share of GDP spent on secondary and tertiary education, the relative strength of IP protection, the relative stringency of the country's antitrust regulations and relative openness to international trade and competition. The authors consider GDP per capita as an indication of the ability of a country to translate knowledge into economic development. Such a position is debatable, since this seems to take for granted that increases in GDP are to be at least partly associated with innovation. This illustrates the difficulty of measuring some of the finer implications of the innovation process quantitatively.

Bartholomew (1997) applies the national system of innovation framework to a model that revolves around three main dimensions: the stock of basic science in the research institutions of a country, the flow of knowledge, and the stock of knowledge in the industry. Each of the three main dimensions is itself divided into a number of variables. These are the variables that are of special interest here, providing possible constituents that should be taken into account. They are: linkages with foreign research institutions; availability of VC; national technology policy; collaboration of firms with research institutions; and interfirm collaborations. Bartholomew also uses a number of variables which reflect the importance of cultural factors in innovation. They include the level of commercial orientation of research institutions; labour mobility; and the national tradition of scientific education.

Bartholomew's model (Figure 2) mostly ignores the dynamics associated with the commercial and industrial aspects of biotechnology, to concentrate on knowledge production. It offers some interesting dimensions for a reflection on performance in the field of biotechnology, especially in relation to basic research and knowledge flows. Bartholomew's use of the model remains limited to descriptive assessments of four nations' systems of innovation.

Another relevant approach is that of Nasierowski and Arcelus (2003) who present a list of indicators to measure the "efficiency" of national innovation systems. Their list of indicators includes:

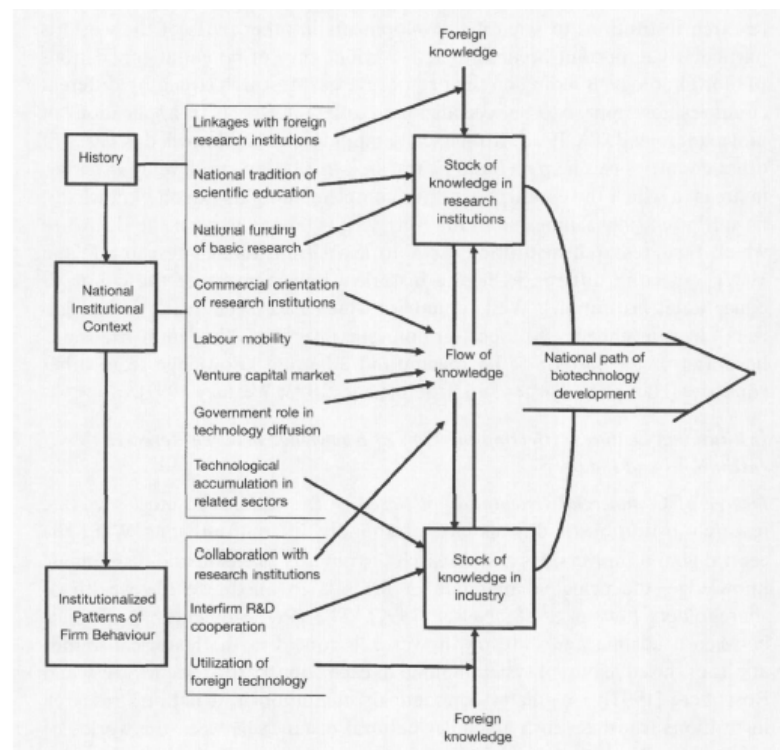


Figure 2 National systems of biotechnology innovation: a framework for analysis
Source: Bartholomew 1997

employment in R&D; population of the country; uncertainty avoidance; and average number of patents by resident. The indicators are regrouped across three general dimensions: national innovation system inputs, moderators, and outputs.

Limits of current theoretical approaches

Although it addresses innovation, and its scale of analysis is the national level, the framework of national innovation systems has been applied with difficulty in the assessment of performance. Balzat and Hanusch (2004) highlight some of the problems facing the application of the concept for the purpose of benchmarking national performance. First, they consider that national systems of

innovation have not yet been properly linked to economic growth. Second, the linkages between national systems of innovation and other systems, such as the labour market and financial systems, are not well understood, although the importance of such linkages are implicit in the theoretical work. Lastly, the dynamics of national systems of innovation are not clearly established and it is therefore difficult to understand how these evolve structurally over time. In addition, Balzat and Hanusch (2004) argue that the use of the national systems of innovation theory for performance studies has been hampered by: 1) mostly verbal descriptions of national systems; 2) a focus on the characterization of specific countries without comparisons with other countries; 3) a lack of formalized methodology.

Despite Balzat and Hanusch's criticism, models such as Bartholomew's (1997) and Furman, Porter and Stern's (2002) are the closest efforts in the literature to a systematic model accounting for most parts of the innovation process, and permitting their measurement. From the models presented above, a few conclusions can be reached:

- Government actions to foster innovation seem to be just as important as knowledge production and application. As such, it is important to measure the efficiency of the policy choices of a nation.
- It is not enough to measure the production of knowledge. Measurements should also include the flow of knowledge from production to commercialization. Bartholomew (1997) highlights the importance of "cultural" or "intangible factors" in the innovation process, mostly in the flow of knowledge.
- Dimensions that are often mentioned as playing an important role in innovation include: the number of full-time-equivalent scientists and engineers; the national tradition of science education; the degree of commercial orientation of research institutions; labour mobility; the share of GDP spent on secondary and tertiary education; university R&D; gross expenditures on R&D; industrial R&D; availability of VC; collaborations; national technology policy; relative strength of IP protection; the relative stringency of a country's antitrust regulations; relative openness to international trade and competition.

Current theoretical frameworks on innovation are mostly anecdotal statements and more or less extensive schematic descriptions of innovation systems or innovation processes. Although these theoretical approaches are interesting heuristic systems, they are far from constituting grand theories of innovation. Nevertheless, they are important clusters of informed opinion on what are the determinants of innovation. One of the common aspects of many of these systems is the insistence on the measurement of "flows" and relations between different parts of the systems. Nevertheless, from a measurement standpoint, it is not clear whether they are superior to existing scoreboards, which do not necessarily attempt to coherently link variables, in part because they do not mention how their validity could be tested and either confirmed or contradicted. This explains why it is important to examine the more micro-level aspects that are expected to determine the performance of modern industries, which is the aim of the next section.

3.2 Empirical evidence on the determinants of innovation and wealth creation

It is impossible to take into account all the constituents of biotechnology innovation since they are simply too numerous. This section presents the variables that are the most often mentioned in the literature on innovation and industrial development.

3.2.1 Role played by science, scientific knowledge and R&D

Given the importance of the concept of the knowledge economy that underpins government support of industries such as biotechnology, it is essential to ask how science contributes to innovation, industrial development and wealth building. There seems to be a perception in policy-making circles that although non-knowledge intensive industries are still important, there is an increasing and fast growing number of sectors relying on knowledge derived from science (OECD 2001b). Salter and Martin (2001) conducted a thorough review of the work linking research to economic growth and returns. Their work suggests that basic research (including what they call “curiosity-driven” and “strategic” research) does seem to have a direct, positive economic impact, albeit they say that it is currently not possible to establish this beyond a doubt due to methodological and conceptual problems. They found the contributions research makes to economic growth include:

- Increasing the stock of useful knowledge;
- Training skilled graduates;
- Creating new scientific instrumentation and methodologies;
- Forming networks and stimulating social interaction;
- Increasing the capacity for scientific and technological problem-solving;
- Creating new firms.

They also report that virtually all econometric attempts at estimating the impacts of research on productivity find positive and relatively high rates of return. An indicator of the amount of public support for research will thus be revealing of a nation’s potential for performance. However, Salter and Martin add the caveat that current knowledge on the relationship between R&D and economic growth cannot be used to determine an optimal level of investment. It is also not known whether additional investments yield constant rates of return, that is, if there are decreasing returns on investment in academic research. Some research indicates that public investment in R&D has greatly varying effects depending on the geographical region (Bilbao-Osorio and Rodriguez-Pose 2004; Rodriguez-Pose 2001).

Bas (2004) considers that government expenditure on biotechnology R&D directly affects commercial performance in the field (see Figure 3 for an estimate of biotechnology R&D expenditure as a percentage of public R&D). He suggests that government R&D expenditure influences the number and size of biotechnology firms in a given country, based on the fact that the three leaders in the field (USA, UK, Canada) are ranked in the same order as their expenditure on biotechnology R&D (US\$ 10.7 billion, 1.4 billion and 0.4 billion, respectively).

Parayil (2005) argues that the knowledge economy will not improve wealth creation and well-being for all; it will rather increase the inequality in the distribution of wealth. The few who possess advanced knowledge will have inordinate gains, while others will lose their resources. This author argues that the growth in wealth associated with the knowledge economy has been linked to reductions in the cost function in economies where the main commodity is knowledge or information. In the case of biotechnology, the development of a drug accounts for much more of the costs than the production of each unit. Parayil considers that once a firm has an increasing return product, the only way that firm can keep its advantage is to create a new one as rapidly as possible.

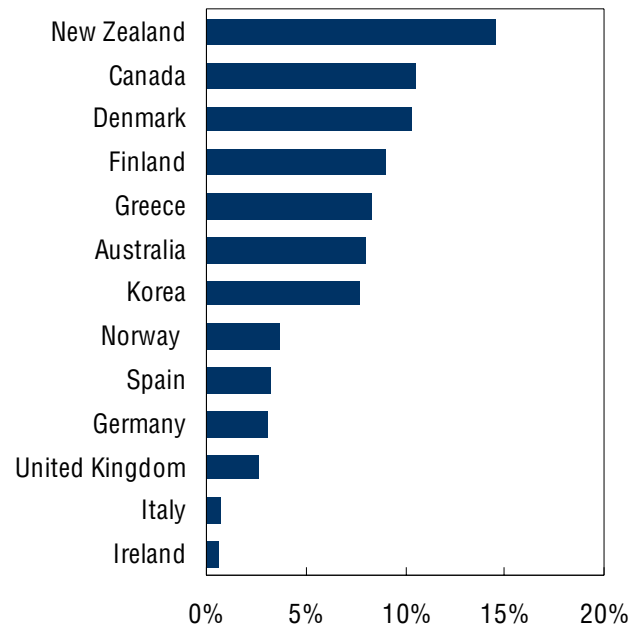


Figure 3 Biotechnology R&D as a percentage of public R&D, 2000
Source: OECD 2003c

Companies that succeed in creating increasing returns on products are in a better position to create new products that also produce increasing returns, and this is accompanied by lock-in effects. Parayil considers that “knowledge production is a self-reinforcing cycle that tends to disproportionately reward some and exclude others” and, as such, tends to favour monopolistic behaviour and diminish competitiveness in the market. Thus, science likely leads to increased wealth, but it could also lead to an increasingly skewed distribution of wealth.

Despite some divergences, the literature converges in suggesting that a strong science base has positive impacts on the innovation process and, consequently, on wealth creation. The next two subsections will explore the role of universities and government research facilities in building up the science base, and the role of technology transfer in exploiting the commercial potential of such a science base.

Role played by universities and by public research

Universities are a central institution of any national system of innovation. Universities act as the main source of basic and applied research, contributing much of the increase in the stock of knowledge that is used in the innovation system (Goldfarb and Henrekson 2003). In addition, these institutions play a vital role in the education of scientists, managers and technicians (Salter and Martin 2001). This latter becomes even more important in the context of the increasing importance of personal attitudes, capabilities and tacit knowledge in innovation (Lee, Wong and Chong 2005). Universities and academic institutions also increasingly participate in the commercialization and the diffusion of the knowledge produced by its scientists (Etzkowitz and Leydesdorff 2000; Henrekson and Rosenberg 2000).

University research is vital in national systems of innovation, and this is as true for basic research as it is for more commercially oriented research. It is especially true in the field of biotechnology, where the building of a stock of basic knowledge is essential to commercial activities given the strong dependence of commercial innovations on advances in molecular biology (Bartholomew 1997; Giesecke 2000; Mangematin *et al.* 2003; McMillan, Narin and Deeds 2000). Some even consider that it is important to conduct basic research to ensure applied research can be sustained in the long run (OECD 2001b). University research has been shown to have a positive impact on industrial R&D (Cohen, Nelson and Walsh 2002). The level of performance of a country's academic system in biotechnology is therefore a valid indication of the potential performance of the country on a commercial scale. In fact, the quantity and quality of academic research are almost universally considered as among the most important dimensions in innovation performance (Klomp and Roelandt 2004; Tijssen, Visser and van Leeuwen 2002). Tijssen (2003 citing VSNU 2002) characterized research excellence in the case of the output by Dutch research groups:

- Originality of approaches and ideas in tackling scientific problems;
- Coherence and cumulative character of the research;
- Contributions made to international scientific developments;
- Quality of scientific publications and of the journals that publish them;
- Other indicators of international recognition, such as positions in international scientific networks and advisory appointments based on scientific reputation.

Because scientists naturally make judgments about the quality of the research of their peers through the course of their work, it is relatively convenient to collect data that reflect research quality. Peer review and citations might be a good way to characterize research that is transmitted in papers. In particular, the quality judgements made by peers through citations as collected through scientometrics are one of the best ways to benchmark national performances in this respect.⁴

Governments often support vast networks of public research organizations, laboratories that are quite often expected to work closely with the industry. These laboratories are sources of knowledge in the same sense that universities are, and they have been shown to have a positive impact on industrial R&D (Autant-Bernard 2001; Cohen, Nelson and Walsh 2002). Public (i.e. government) research organizations can be widely considered to show the same dynamics as universities, with a few exceptions such as the presence of students in the case of the latter and more interdisciplinary research and sometimes higher-cost equipment in the case of the former (Bozeman 2000).

Roles played by the diffusion of knowledge and technology transfer

Although a stock of basic scientific knowledge is an essential ingredient in a national system of innovation, it needs to be transferred to have an impact on industry. Hence, diffusion of knowledge and technology transfer are seen as fundamental factors in the contribution of the academic world to national systems of innovations (Goldfarb and Henrekson 2003). Technology transfer is often

⁴ For a review of how scientometrics can be used to evaluate research quality and benchmark performances in universities, see Van Raan (2003).

seen (though sometimes ill-advisedly) as an indication that efforts are being made by scientists to address commercial or societal concerns (Bozeman 2000).

An important aspect of the knowledge produced in biotechnology and in innovation systems in general is its tacit nature (Giesecke 2000; Lawson and Lorenz 1999; Salter and Martin 2001; Zucker, Darby and Armstrong 2002). A technology or knowledge advance produced in an academic context, and which may lead to a new biotechnological product, may not be “transferable” to industry simply as a set of objects and text. The knowledge is often embodied within the inventors, and is part of their know-how and routines. This links technology transfer to mobility of researchers, academic entrepreneurship and university-industry collaboration and further underlines the importance of universities as providers of human resources. Zucker, Darby and Armstrong (2002) examined the importance of technology transfer in the success of biotechnology firms. They reported that firms employing star scientists or the collaborators of star scientists generally hold patents that are frequently cited and are of high quality, and that these firms attract more VC. This the authors say is because star scientists are usually the originators of invaluable tacit knowledge which greatly adds to a biotechnology firm’s competitiveness. That technology transfer from academia to the biotechnology industry is crucial is perhaps more convincingly demonstrated by the fact that most DBFs are university start-ups or spin-offs (Mangematin 2003; Niosi and Bas 2003), that is, firms through which the tacit knowledge and problem-solving abilities and skills of academics are directly transferred to the commercial environment (Salter and Martin 2001).

Bozeman (2000) has analyzed at length the dynamics and institutional implications of technology transfer and listed a number of elements that might be used as indicators to measure the intensity of technology transfers: number of licenses, number of technology transfer offices, number of university patents, number of start-ups and spin-offs. Siegel *et al.* (2004) identified the output of university/industry technology transfer as including licenses, royalties, patents, sponsored research agreements, start-up companies, invention disclosures, students, informal transfer of know-how, product development and economic development. Of these, the most commonly used indicators are number of patents (Archambault 2002; Meyer 2000), number of licenses (Shane 2004), amount of royalty revenue from these licenses; number of technology transfer offices; and number of spin-offs and start-ups. An example of some of these indicators being put into practice can be found in a report by Powers (2003).

Technology transfer also occurs between countries and between firms, which explains why scientific research is considered to be a public good: it cannot be appropriated completely (Geroski 1995; Mansfield *et al.* 1977). Indeed, the scientific ethos pushes researchers to publish as much as possible, which includes publishing in international journals enabling scientists from other countries to appropriate scientific knowledge. Nonetheless, it is necessary to perform scientific research in order to be able to absorb leading edge science. Thus, although science is diffused outside the boundaries of countries, it can also percolate towards the inner parts of systems and the rate of percolation is not only a function of the intensity of research performed elsewhere, but also a function of the level of indigenous scientific activities. The more science that is conducted within a system and the more

scientists that are working on a problem, the greater will be the capacity to absorb scientific knowledge from research performed in foreign countries (OECD 2001b). Salter and Martin (2001) thus argue that nations cannot hope to simply “free-ride” on the world scientific system. To be able to absorb knowledge produced in other countries and to understand the cutting edge developments in a particular field, a nation must itself be performing some research in that field even if not to at the same level. The capacity to absorb and understand the new knowledge is important since technology transfer from foreign countries can be an important source of economic growth (Cameron, Proudman and Redding 2005). Thus, indicators of scientific excellence are not only proxies for the capacity to create new knowledge, but also of the capacity to absorb scientific knowledge being created elsewhere.

Collaboration is another important means of technology and knowledge transfer. Belderbos, Carree and Lokshin (2004) find that the most common reason for doing collaborative R&D is the knowledge spillovers that occur between firms. More specifically, collaboration is seen as a way to raise the level of spillovers and to internalize them, especially in combination with IP protection. The rationale for R&D collaborations identified by these authors is: sharing risks and costs in the face of uncertain technological developments; shortening innovation cycles; improving efficiency through mechanisms such as economies of scale or scope, or synergetic effects; acquiring knowledge through the common monitoring of technology and market developments; and acquiring greater ability to deal with regulations and industry standards (Belderbos, Carree and Lokshin 2004). Similarly, Bas (2004) mentions that alliances enable firms to: reduce risks; access financial, human and technological resources; decrease R&D costs; access intellectual property; decrease the development and life cycle of products; access local or international markets which would otherwise remain inaccessible; and learn faster. Niosi (2003) adds that the timing of an alliance may lead to increased growth and performance, but that alliances should not be considered as an automatic indication of success. The intensity of collaborations is therefore a dimension that should be considered in the creation of a scoreboard. National and international levels of collaborations between firms, between firms and public institutions, and other partners could be compiled and compared.

Another important aspect in the diffusion of knowledge is mobility of human resources. Facilitating mobility back and forth between industry and academia and even government is a good way to encourage innovation. Mobility favours the flow of knowledge between actors and institutions. For Bartholomew (1997) mobility insures the accessibility of firms to the basic knowledge developed in academia, and to technological and human capital. At the same time, mobility also increases the awareness of scientists about the requirements of commercial markets, thus enhancing the flow of knowledge, and especially the tacit knowledge related to most high technology developments. Lawson and Lorenz (1999) provide a good overview of the problem of tacit knowledge in the context of the innovation process. If knowledge is difficult to transmit from the originating institution, then the personal involvement of the inventor becomes all important. Academics who develop new processes, know-how, and knowledge will most likely need to participate directly in the industrial appropriation of their inventions. But they need to be able to do so at little cost to their academic careers if remaining in academia is a primary focus. Thus institutional mobility becomes an

important and a primary condition for the successful transfer of technology from the academic base to industry.

The possibility for academics to engage in work that is not typically associated with academia is affected by the institution's social conditions, and particularly the incentive structure in place (Goldfarb and Henrekson 2003). If the pursuit by academics of industrial science for financial rewards is frowned upon, mobility is correspondingly restricted. A system that allows some mobility is necessary to promote a modicum of entrepreneurship. Scientists need to be able to freeze their tenure to take time off to build start-ups or spin-offs, with no adverse consequences for their academic careers (Goldfarb and Henrekson 2003). However, too much firm to firm mobility might have undesirable consequences for firms. For instance, high mobility between firms will reduce the incentive to invest in R&D, since results might be transmitted to a competitor through employees moving to another enterprise (Moen 2005).

Although potentially a powerful indicator, mobility is difficult to measure quantitatively: number of academics involved in relationships with industry might be measured using bibliometric methods.

3.2.2 Role played by human resources

The availability of human capital is often cited as a bottleneck for innovative industries (Schienstock and Tulkki 2001; Smith 2004). Furman, Porter and Stern (2002) report that growth in the numbers of scientists and engineers seems to be associated with economic growth – but the problem with such correlations is to establish the direction of the causal relationship. The quantity and quality of the workforce as well as the entrepreneurship of the technical personnel seem to be determining factors in the formation of new DBFs (Hsu, Shyu and Tzeng 2005). Human resources also may be the principal means for technology transfer (Hsu, Shyu and Tzeng 2005; Zucker, Darby and Armstrong 2002; Zucker, Darby and Torero 2002).

Although it is important in terms of personnel costs for industry to keep to a minimum the numbers of its scientists, technicians and managers, it is essential to have enough skilled personnel. Lee, Wong and Chong (2005) positively associate human capital and social capital to R&D outcomes. Human capital includes the level of education, past work experience, and training. The last two variables might be interesting to consider, although these authors found that experience and training had no or even a negative effect on R&D performance. Bas (2004) considers that intellectual capital is usually measured by calculating the number of years of education of a population in a field. As previously mentioned, Zucker, Darby and Armstrong (2002) found that firms with connections with star scientists tended to perform better, and to obtain more VC and consequently to perform better financially. Similarly, Deeds, DeCarolis and Coombs (1999) noted that researchers with outstanding academic track records are more likely to be successful in a commercial setting: “Our results indicate that there is a strong positive relationship between the impact—as measured by citations—of a team’s prior research in the academic community and the productivity of that team in a commercial research laboratory” (Deeds, DeCarolis and Coombs 1999: 226). These results support the relevance of using scientometrics to measure the quality of the scientific output in a system.

Entrepreneurial stance

To some, innovation is not so much a process, as a culture, a mindset or a set of attitudes. Probably the most frequently mentioned attitude related to innovative capability is entrepreneurial stance. This is part of Schumpeter's heritage in that he considered entrepreneurship (along with technology) to be one of the most important drivers of the economy, one that should be considered alongside more classical production factors such as labour, land and capital (Carayannis and von Zedtwitz 2005). Entrepreneurship can be defined as the willingness to seize commercial opportunities in spite of the risks and uncertainties (Glassman *et al.* 2003; Carayannis and von Zedtwitz 2005). This fits perfectly with the high technology ventures stressed in most national systems of innovations, since these can bring about substantial rewards, but often face unfavourable conditions (Van Geenhuizen 2003). Entrepreneurship is considered to be a central concern for countries looking to improve national performance in biotechnology (Van Geenhuizen 2003). For instance, in an effort to improve the environment for biotechnology in the Netherlands, Van Geenhuizen attributes great importance to reducing the barriers to entrepreneurship. She mentions that while high-technology entrepreneurship accounts for 25% of new ventures in the US and for 10% of new ventures in Europe, the Netherlands can only claim 6% to 7% of their new ventures as being high-tech. She mentions several points which negatively affect entrepreneurship in the Netherlands: time and money constraints in the setting of private limited liability companies; stigmatization from failure/bankruptcy; extensive and strict regulation for new firm establishment; lack of VC; under-representation of entrepreneurship in the education system; and lack of incentives and drive for academics to become entrepreneurs.

Governments can play a role in stimulating entrepreneurship by formulating policies that facilitate access to VC, that remove any stigma from business failures, and that reduce the burden of tax and labour protection regulations on SMEs (Henrekson and Rosenberg 2000; Van Geenhuizen 2003). Universities and academia can develop entrepreneurial skills and abilities in their students and staff (Röpke 1998) and allow their scientists to take breaks to pursue a business career. In addition, industry can foster entrepreneurship within its own ranks (Carayannis and von Zedtwitz 2005).

Van Geenhuizen (2003) has shown that government policies have an important impact on willingness to become an entrepreneur, but this aspect is relatively difficult and costly to measure. Entrepreneurship could also be measured directly by looking at the number of spin-offs, start-ups and other new high technology ventures founded by academics, public laboratory researchers and other types of entrepreneurs.

3.2.3 Role played by financing, investments and venture capital

The link between innovative activities and the availability of VC has been clearly established (Kortum and Lerner 2000; Lerner 1999), and VC is vital to the biotechnology industry. For instance, Niosi (2003) argued that a fluid VC environment and the ability of firms to tap into it are considered to be major factors for growth and success. Bas (2004) strengthens Niosi's claim with statistical evidence that access to VC is positively correlated with fast growth. Indeed, as Mangematin *et al.* (2003)

pointed out, a proportion of firms involved in biotechnology can expect VC to be their main source of liquidity for a good part of their business life. In a study of what they call “fast-growing” biotechnology SMEs, they found that for 19 out of 23 such firms, venture capitalists were indispensable partners. Availability of VC plays a large part in stimulating entrepreneurial behaviour and the easier it is to obtain, the more likely scientists will be tempted to start their own companies (Carayannis and von Zedtwitz 2005). Figure 4 shows that, in relative terms, in 2001 Canada was the country with the highest levels of VC.

Giesecke (2000) examined how VC contributed to the development of the US biotechnology industry. She argues that VC was essential for setting up very unique configurations of small specialized research units in high-technology clusters close enough to easily exchange tacit knowledge. VC provided financing for research, until the industry came up with the first patents and products, a role that is still very necessary today.

Also important, the VC sector made a lasting contribution in the form of managerial and business know-how about running a high-tech company. This point is supported by Henrekson and Rosenberg (2000) who mention that in biotechnology start-ups that are supported by a VC firm, the VC firm often plays an extremely active management role.

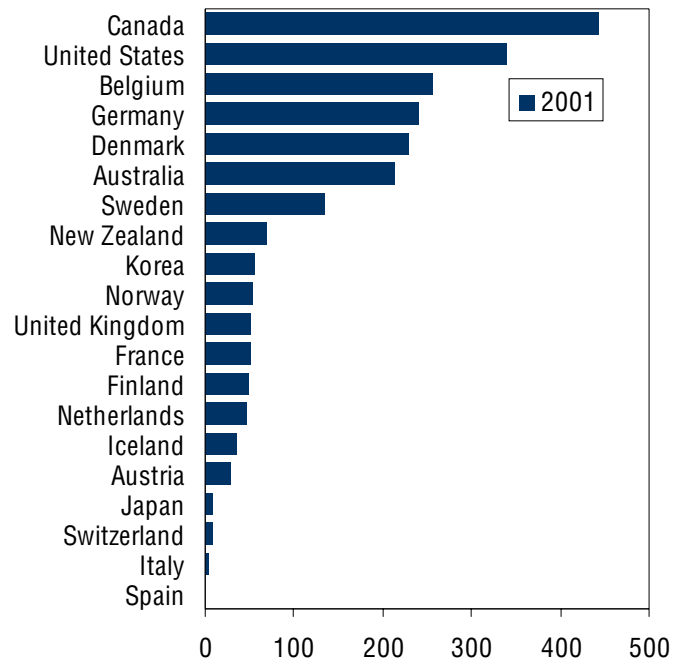


Figure 4 Biotechnology venture capital per million units of GDP, 2001
Source: OECD 2003c from OECD Venture capital database, April 2003

The backing of a VC firm influences day-to-day decision making and affects the long-term strategy of the firm. The VC firm will often be represented on the firm’s board of directors. All of this has an important impact on the growth of the firm:

An extremely important feature of control in the hands of the venture capitalist is that financial support is doled out in stages, with no more money made available than is necessary for the firm to reach the next stage, so that there are multiple opportunities to evaluate performance at each stage and to terminate support if performance is deemed to be unsatisfactory. The arrangement is one that is calculated to discourage opportunistic behaviour and to strengthen commitment to the firm’s long-term prospects for success, or at least to a successful IPO that will create a profitable payoff to the VC firm (Henrekson and Rosenberg 2000: 34-35).

These distinctive features of VC firms show that they cannot be replaced by government grants or loans. Thus, the availability of VC is usually considered to be a very important indicator of the health of the biotechnology industry. This dimension can be further characterized by examining the number of projects financed, and the amount of capital granted per project (examples can be found in Ernst & Young's annual studies; see also MacDonald and Associates 2004). It might be interesting to look at the viability of the venture capital firms themselves, especially those dealing exclusively or in great part with biotechnology, and to measure the returns to venture capitalists on investments in biotechnology companies.

Once a DBF is well established, it might choose to diversify the sources of its income to public investments. The timing of an initial public offering (IPO) identifies the point at which a company starts offering its shares to public investors. This is often, although not always, accompanied by a listing on the stock exchange, (Cumming and MacIntosh 2003). This process is often seen as an important step in the development of a DBF. Chang (2004) calls it a "performance milestone", a signal that a firm is ready for further growth. An IPO gives the venture capitalists who invested in the company the opportunity to reap some return by selling their shares in the company. However, they may decide to keep their shares in the hope that they will increase in value (Mangematin *et al.* 2003). In infusing a significant amount of capital into a firm IPOs enable firms to avoid the fate of a lot of DBFs, that is bankruptcy due to lack of finance and heavy debt loads (Deeds, Decarolis and Coombs 1997).

IPOs are of interest in this study for two reasons. First, the results of IPOs are useful indicators of firm performance. Deeds, Decarolis and Coombs (1997) and Stuart, Hoang and Hybels (1999) measure the success of IPOs by the amount of capital raised. Chang (2004) and Stuart, Hoang and Hybels (1999) take the timing of the IPO, as measured by the number of months since the founding of a start up, as a measure of performance. Second, since IPOs offer a variety of benefits to biotechnology firms, they in themselves can be considered as important contributors to growth in biotechnology. Government regulation will have an effect on the IPO process, including the frequency with which venture capitalists will choose to exit at that point (Cumming and MacIntosh 2003). Thus, it might be interesting to evaluate the extent to which the institutional arrangements of a country are conducive to the IPO process (see in this respect the Institute for Management Development (IMD) World Competitiveness Reports (published annually) and described more fully in section 3.2.5).

3.2.4 Role played by firms

Industry is a focal point of biotechnology innovation scoreboards. Firms use innovations to improve their competitiveness by creating better products or by enhancing their production processes (Conceição, Heitor and Veloso 2003; Gibbons *et al.* 1994; Freeman 2004). Profitability and growth of innovative firms are among the main goals of most innovation policies, the assumption being that they eventually translate into outcomes such as improved quality of life and prosperity (OECD 2001b).

Adam Jr. *et al.* (1997) provide some examples of the measurement of firms' financial performance which include: past year's net profit as a percentage of sales; past year's return-on-assets; past three-years' return on assets; past three -years' average sales growth. These could be combined with measures of R&D inputs to examine how research correlates with financial performance. Another indicator is the turnover of biotechnology firms, which can be expressed as a percentage of gross national product, to compare the level of performance in countries of various sizes (Schienstock and Tulkki 2001). Statistics Canada's Biotechnology Use and Development surveys (BUDS) are also sources of useful data on various variables linked to firms' innovative potential and financial performance (McNiven, Raoub and Traore 2003).

The product pipeline of a firm is considered to be a very important indicator of its performance. It determines a company's future cash flows. DeCarolis and Deeds (1999) consider that products in development are physical manifestations of accumulated stocks of organizational knowledge that are strongly linked to firm performance. An evaluation of the total number of products in the biotechnology pipelines of various countries might be a good way to benchmark performances. This view is confirmed by the fact that the state of a firm's pipeline will have a direct effect on the amount of money it is able to raise from an IPO (Deeds, DeCarolis and Coombs 1997).

Dedicated biotechnology firms

At the core of the national systems of biotechnology are the DBFs. According to Niosi and Bas (2003), most DBFs are start-ups or spin-offs from university research departments. Mangematin *et al.* (2003) qualify these firms as being the "nexus" of the biotechnology sector, since they are linked both to the scientists in the academic world and to the pharmaceutical companies, which will often end up commercializing the discoveries made by these firms. Mangematin *et al.* (2003: 622) argue that:

Development of the biotech sector is based on the entry of a large number of SMEs; the biotech sector is often described as a large and highly turbulent population of innovators; SMEs are a leading force in a science push context, while the role of large firms is mainly to integrate new discoveries into their products after they have been developed by SMEs.

DBFs do not usually function in autarky. They are highly dependent on external institutions and on other firms. Due to their small size, DBFs often need to access scientific knowledge and competencies developed in the academic world. They also need to be able to raise capital on a recurrent basis (Mangematin *et al.* 2003). The connection with the academic world is so important that it is considered a precondition for the growth for these firms. At the same time, DBFs need to commercialize the results of their efforts, and this is most often achieved by partnering with large companies to provide "specific, materials, technologies, know-how, or expertise" (Mangematin *et al.* 2003). These characteristics of DBFs highlight the importance of examining and measuring the three aspects : technology transfer and links to the university knowledge base; the venture capital sector; and the pharmaceutical and large enterprise sector.

Firm spending on R&D is also often seen as a sign of potential success, and R&D is considered to be the core competence of DBFs (Niosi 2003). Thus, measuring the level of R&D expenditures might be

an appropriate way to characterize the level of maturity and growth of these firms. Granstrand (1998) mentions that sales are positively correlated with R&D expenditure. It would thus seem that the intensity of a DBF's efforts in the development of new products is often a determinant of future success, and thus an indicator of future performance. However, there is a danger of decreasing returns on R&D (Graves and Langowitz 1996), and therefore this indicator should be interpreted with caution.

Patents play an essential role in the success of DBFs. Patents are seen by VC investors and commercialization partners as valuable assets, which puts firms in a favourable position to obtain complementary assets and skills and enables them to reach the IPO stage more rapidly (Baum and Silverman 2004). Bas (2004) provides statistical evidence that patents are a very important factor in explaining biotechnology firms' growth. Number of patents is a good indicator of firm performance and, in aggregate, of the performance of the national system of innovation.

BioQuébec (2004) associates the vitality of firms with dimensions such as the stage of development of products (pipeline), public offerings and capital raising, revenues, cash in hand, length of potential autonomous functioning without external capital, number of workers and employees, number of alliances with pharmaceutical or other types of biotechnology-user firms.

Thus, indicators of the overall performance of a country's DBF sector could be: number of DBFs, DBF revenues, number of employees, R&D spending, strength of the product pipeline, number of patents, capital raised, and average period of autonomous functioning. A number of these indicators are already available, for example in Statistics Canada's Biotechnology Use and Development surveys (see for instance McNiven, Raoub and Traoré 2003).

Pharmaceutical and other user firms

The goal of most health biotechnology DBFs is to strike deals with pharmaceutical companies, and for those not involved in the health sciences, another large company. For Mangematin *et al.* (2003), the advent of biotechnology was a "competency destroyer", which left large pharmaceutical companies in a position where collaboration with or subcontracting to small research and service oriented companies became preferable to conducting research in-house. Typically, DBFs will develop drugs and other biotechnological products up to the point of commercialization. At that point, they will call upon pharmaceutical companies that have the industrial capacity to manufacture and commercialize the end-products (Mangematin *et al.* 2003). It is estimated that pharmaceutical firms spend or will spend up to 30% of their drug discovery budget on external collaborations, primarily with DBFs (Van Geenhuizen 2003). The importance to DBFs of partnerships with large pharmaceutical companies is acknowledged in the industrial and the financial spheres. Potential investors in DBFs interpret such partnerships as positive signals (Mangematin *et al.* 2003) and are more likely to commit to financing these companies.

For Feldman and Ronzio (2001), the presence of a large number of bio-manufacturers and reliance of DBFs on external firms for commercialization is not necessarily a sign the biotechnology industry's vitality. These authors see such firms as depriving DBFs of the capabilities and skills they

would gain through manufacturing the products themselves. Manufacturing could be a knowledge-generating activity which would provide firms with a potential regional advantage. For Feldman and Ronzio “The R&D focus merely reflects the stage of the industry’s development and should not be normatively understood as an identifying hallmark of the biotechnology industry”. It seems, however, that the consensus is turning against such an interpretation and that outsourcing collaborations are considered to be a positive constituent of the national systems of innovation in biotechnology.

Thus, an important dimension associated with the large enterprise and pharmaceuticals sectors is the receptivity and willingness to collaborate with DBFs, and this could be added to the more traditional indicators of sector performance: revenues, employment, R&D spending, and number of firms. The problem with these larger enterprises, however, is that traditional indicators of performance such as revenue and employment levels, and R&D expenditure, will not be associated only with biotechnological products. Indeed, most large enterprises produce and commercialize a wide array of products. Special care must be taken therefore to insure that distortions are not introduced into the data.

Clinical research organizations and other service organizations

Health sector biotechnology encompasses a specific set of companies, that is clinical research organizations (CROs). As Niosi and Bas (2003) pointed out, this relatively new area of the biotechnology sector is hoping to cash in on the opportunities presented by the pre-clinical and clinical phases of drug development. These phases account for about half of the US \$550 to \$800 millions it costs to develop a new drug in the health biotechnology sector (Niosi and Bas 2003). For Piachaud (2002), who studied this sector specifically, CROs must be seen as vital elements of the R&D process in health biotechnology. Dealing with CROs offers a number of advantages for biotechnology companies, including: converting fixed costs into variable costs; accelerated entry of products to the market; easier termination of weak projects; concurrent development of products on a global level; and access to additional and potentially unique skills, knowledge and technology (Piachaud 2002). These advantages are even greater in a context where there is strong competition among CROs.

A vigorous clinical research sector will thus have a positive impact on product development and success, and on market receptivity. This is especially true in light of the money spent on drug development, and the low success rate (Piachaud 2002). As such, it is a constituent of the innovation process, especially in the social appropriation of biotechnology innovations, as understood based on *The New Production of Knowledge* (Gibbons *et al.* 1994). Additionally, the sector provides leverage to economic growth, creating employment and increasing revenue. According to Niosi and Bas (2003), this sector is one of the fastest growing in the industry.

A well performing CRO sector, which could contribute to the performance of a national biotechnology system, would be characterized by: a large number of firms; significant revenues; and high levels of employment. The intensity of transactions and links between CROs and the

biotechnology sector could be associated with the dimensions used to measure the exact part of the CRO sector to be accounted for in an evaluation of the biotechnology sector.

3.2.5 Role played by governments

Governments can have a great influence on the innovation performance of a country. The OECD (2001b) identifies four ways that governments can stimulate the development and diffusion of innovations within their national systems:

- establishing appropriate incentives for innovation;
- ensuring the generation of new knowledge;
- making their own investments in innovation more effective;
- improving interaction between the main actors in the innovation system, that is, universities, research institutes and firms.

Appropriate incentives for innovation mostly arise out of a well balanced IP protection framework that provides firms with the protection necessary to be competitive while not unduly restricting the diffusion of knowledge. Governments ensure the generation of new knowledge by providing funding for basic and applied research, whether private or public, and for VC for innovative firms. In the case of the private sector, governments can provide grants, subsidies, loans or tax credits. Making investments in innovation more effective implies that governments take the necessary measures to insure that the optimal level of help is obtained. This means, in particular, making sure that there are no vested interests in funding, and that it has corresponding social returns, and ensuring that investments in private R&D do not replace private initiatives or crowd out areas such as VC where private finance might be able to flourish. Finally, improving interaction between the main actors in the innovation system implies facilitating the mobility of scientists, fostering technology transfer and the flow of knowledge from the public science sector to industry, and fostering co-operations between firms (OECD 2001b). Two aspects that were not mentioned by the OECD and where governments have an important role are the regulation of clinical trials (Hsu, Shyu and Tzeng 2005) and taxation (Henrekson and Rosenberg 2000; OECD 2001b).

The OECD advocates an interventionist approach. Although this seems to be the dominant discourse in policy and innovation research circles, it must be remembered that there are other approaches. Some authors have shown that economic performance based on high technology and R&D is not necessarily tightly linked to government support. In particular, Colombo and Delmastro (2002) reviewed the rationales which may call into doubt public support for high technology firms. Arguments for public support seem to concentrate on supposed market failures which prevent fair access to inputs such as finance for new high technology firms (Bozeman 2000). Also, its supporters say that innovations developed in biotechnology firms are of such a revolutionary nature that positive externalities will largely compensate for investment. Detractors of such a view suggest that government support will slow down market selection, by supporting “lame ducks” and diminishing overall competitiveness and thus the efficiency of the economy (Colombo and Delmastro 2002). The interest in this discussion lies in the possible bias that might arise were to adopt indicators

measuring the policy choices of countries. Of all the factors that may affect the innovation process, policy choices are probably the most contentious and subjective to debate. Therefore, associating good innovative performance with a certain policy choice is risky and might denote a subjective position of the evaluator. Other aspects involve factors relating to policy choices, and caution must be taken in examining them.

Regulation and the IP framework

An important aspect of government intervention that influences the activities and performance of biotechnology firms is the establishment of regulation aimed at protecting IP. The role of IP regulation is to provide incentives for private companies to innovate, and for researchers to obtain a temporary monopoly on an invention in exchange for public disclosure. On the other hand, a protection regime that is too strong may stifle the diffusion of knowledge, a factor that is essential to the innovation process (CRIC, University of Manchester and UMIST 2000).

Gould and Gruben (1996) tackled this issue a decade ago and provide some insights. One argument for weak protection of IP is that free access to information stimulates growth and further innovation. Also, strong protection is perceived as potentially encouraging monopolistic behaviour by firms. Countries who mostly consume the products and processes of inventions may also argue in favour of weak protection. Gould and Gruben support the case for strong protection by showing that it stimulates innovation, that social benefits are much higher than the benefits gained by the inventor, and that lack of protection may deter the diffusion of cutting edge industrial technology. Through a demonstration of their own, which associates economic growth with patent and degree of IP protection, Gould and Gruben find that stronger protection is correlated with high economic growth. This, however, mostly applies to liberal and open economies. Colyvas *et al.* (2002) show that while IP protection may spur development when the knowledge is being transferred from the university, in other cases it may have no or even adverse effects.

Goldfarb and Henrekson (2003) show that where the IP rights are awarded matters. In some instances, mostly in countries where universities are independent and competing entities, commercialization of knowledge is favoured when the IP rights are awarded to the institution rather than the individual inventor(s).

One of the important aspects of regulation, especially for health biotechnology, is the approval of new substances. The regulatory infrastructure should allow for efficient pharmaceutical product registration processes and clinical trial systems (Hsu, Shyu and Tzeng 2005). As Furman, Porter and Stern (2002) point out, national policies can also affect productivity through antitrust regulations, and regulations that affect the country's openness to international trade and competition.

The level of regulation may be estimated using the IMD World Competitiveness Reports which provide Likert score variables (1-10) on dimensions such as IP, openness to international trade and competition, and efficiency of antitrust laws. These national scores are obtained by surveying leading company executives (for an example of the application of these scores, see Furman, Porter and Stern 2002).

Fiscal incentives

A mechanism commonly used by governments to support development in high technology sectors is to create incentives through different fiscal measures including special tax rates, tax credits, loans and grants. The fiscal pressures on companies may often be a determinant of their success (Henrekson and Rosenberg 2000). Tax credits for R&D are a potent mechanism to encourage spending on innovative activities, while leaving firms free to choose how to conduct their R&D efforts. Tax credits are a form of non-intrusive subsidy since it is still the market that ultimately determines the orientation taken by firms (Hall and Van Reenen 2000). Bas (2004) contends that the 20% tax credit on R&D in the US has contributed to the country's dominant position in biotechnology.

Leyden and Link (1993) tend to reject the affirmation that R&D tax credits are an efficient way to foster growth in biotechnology. Looking at the expenditure of the US, Canadian, Swedish and Japanese governments on R&D tax breaks, they say that the benefits are rarely worth the cost. Leyden and Link do not seem to represent the consensus however, and other writers have reached alternative conclusions. Hall and Van Reenen (2000) say that R&D tax credits are likely to become an increasingly important measure to encourage innovation, as more governments turn away from direct grants. These authors consider that a dollar in R&D tax credit results in a dollar of additional R&D for the beneficiary firm. Based on data from 1979 to 1997, Bloom, Griffith and Van Reenen (2002) found that R&D incentives increase R&D spending by 10% of their value in the short term, and by 100% in the long term.

This evidence suggests that a country's taxation system might in part explain performance. One indicator for this dimension might be the amount governments spend on tax breaks and other incentives. Another might be the amount of after-tax benefits received by a firm from investing in R&D (an example of this can be found in OECD 2001b).

Governments also help firms directly through public investments. Governments often provide subsidies for R&D. Klette, Moen and Griliches (2000) reviewed recent literature on the topic and found that most studies report a positive effect of public subsidies on the level of R&D conducted by firms. A possible problem with these types of government interventions is that public R&D funding might substitute for private R&D funding, whereas the desired outcome would be that public R&D funding would encourage further private funding. David, Hall and Toole (2000) find that in about a third to a half of econometric cases, public R&D funding did substitute for private funding. The current scientific literature does not seem to be concerned with whether loans or grants are the preferred method of public subsidy for R&D.

Science parks, incubators and clusters

Biotechnology firms and related institutions are sometimes grouped in the same geographical locations, in what are called "science parks" or "incubators", and these clusters of firms are often supported by local, regional, or national governments. This type of support is considered to be an important mechanism for improving a sector's performance through the fostering of

entrepreneurship (Carayannis and von Zedtwitz 2005; Colombo and Delmastro 2002; Grimaldi and Grandi 2005). Grimaldi and Grandi (2005: 111) argue that:

The incubation concept seeks an effective means to link technology, capital and know-how in order to leverage entrepreneurial talent, accelerate the development of new companies, and thus speed the exploitation of technology. Over the last 20 years, increasing importance has been attached to incubators as mechanisms for enhancing the economic and technological development of countries by promoting the rise of promising entrepreneurial ideas and encouraging the growth of newly established companies.

Colombo and Delmastro (2002) studied the effects of science parks in Italy. The authors mention that science parks and incubators appear to play positive selector roles. Firms located in science parks have higher quality personnel and human capital, and have founders and employees with richer educational backgrounds and related experience. Italian firms located in science parks had easier access to public subsidies. These firms also displayed faster growth than their off-park counterparts, and had proportionately larger numbers of employees. They also had more formal commercial and technical level cooperation. Science park firms, however, did not show significantly higher levels of R&D intensity and patenting activity. It would thus seem that location in science parks and incubators is no guarantee of across the board growth for firms.

Carayannis and von Zedtwitz (2005) highlight an important aspect of why science parks and incubators could be considered important constituents of the innovation process: they stimulate entrepreneurship. The theory is that, in the face of certain risks, and a higher than average possibility of failure, scientists with unique knowledge and interesting inventions might be more willing to become entrepreneurs within structures such as science parks and incubators. In other words, science parks and incubators, as much as technology transfer offices, might be the link necessary for putting rather theoretical or academic knowledge into practice, working for economic and social prosperity.

Carayannis and von Zedtwitz (2005) further characterize science parks and incubators. Such institutions can increase competitive advantage through a geographical and/or industrial focus. Indeed, by concentrating on established networks in a certain region or in a certain industrial sector, incubators may create synergies among similar incubees, develop specialized competencies and know-how, and/or develop extensive local networks. The authors identify five elements that are almost always connected with incubators: access to physical resources; office support; access to financial resources; entrepreneurial start-up support; and access to networks.

Importantly, even though they may be popular with local governments that want to attract and support the development of high tech firms, it appears that the presence of business incubators and science parks is not in itself an indication of good performance. The literature tends to show that such groupings can improve firm vitality in high-technology sectors. Thus, the presence of science parks and incubators might indicate higher potential for those innovation systems than for systems without them. There is no proof, however, that a system performs better if there are incubators and

science parks. Furthermore, there is no consensus about whether incubators and science parks are indeed efficient in accelerating the commercialization of knowledge and the growth of high technology firms. For instance, in contrast to the findings of Colombo and Delmastro (2002), Shearmur and Doloreux (2000) in examining the economic performance of Canadian cities with science parks and those without, found they had no impact on high-tech employment growth.

A concept frequently associated with incubators or science parks is that of clusters. Rocha (2004) provides a definitive review of the theories on clusters and how these mechanisms are supposed to contribute to economic growth at firm, regional and national level. There are a number of theories related to clusters. A common definition of clusters is a group of firms with converging interests, located within the same geographical area. Reviewing the empirical evidence available on the possible contribution of clusters to competitiveness, growth and development Rocha found that most were case studies with limited generalizability. Furthermore, most empirical studies on the impact of clusters suffered from severe methodological limits and shortcomings. The current limited empirical evidence prevents the inclusion of clusters as important constituent of the innovation process.

3.2.6 Theoretical and empirical insights for the construction of scoreboards

This section examined the literature on the current understanding of the variables that influence innovation biotechnology, and how they can be measured. The objective was to determine whether it is possible to establish a list of factors in the field of biotechnology that have a causal influence on wealth creation. The objective of a scoreboard is to associate the relevant variables and indicators in order to measure and to identify areas where Canadian performance might be improved.

Section 3.1 presented some analytical frameworks of innovation to inform this study. These frameworks highlighted important aspects of the innovation process and some of its more interesting characteristics. The theories of *The New Production of Knowledge* and of national systems of innovation highlight the importance of treating innovation as resulting from networks of heterogeneous actors, most importantly, firms, universities and governments. Section 3.2 reviewed the literature on specific factors influencing innovation. The factors, which need to be taken into account when measuring biotechnology performance, include the following categories: science and R&D; human resources; financing, investment and venture capital; firms; and government intervention.

Section 3 described the innovation process in biotechnology, but with little regard to its becoming operational. This exercise was useful to give a theoretical grounding for the scoreboard, but pragmatic constraints make it infeasible to measure some of the variables, even though they may play an important role in the innovation process. The next section will review the indicators used in the scoreboard in terms of practice. This review will provide an invaluable point of comparison for the theoretical work described in this section, and will contribute to the final selection of indicators on which the scoreboard will be based.

4 Insights from existing scoreboards

Experts have for years been trying to develop indicators that would provide a clear quantitative measure of R&D and thus of the innovative process. However, measuring the performance of science-related projects is inherently difficult because of the nature of the innovative process. Furthermore, the availability of these indicators varies amongst countries rendering international comparisons difficult. This section briefly describes the different indicators that have been used to measure S&T (Section 4.1) and examines in greater detail indicators used by the European Commission and by the OECD to measure the innovation process in the biotechnology sector (Section 4.2). Reviewing these indicators provides a sense of the work done so far on biotechnology scoreboards, the obstacles that have been encountered, and what should be avoided. It also provides the empirical and pragmatic counterpoint to the indicators suggested by the review of innovation theories.

4.1 General science and technology scoreboards

The different S&T indicators (see Table I in the Appendix) can be classified under three general sub-classes: 1) patents and scientific publications; 2) private and public sector personnel involved in R&D; and 3) private and public investment, financing, and R&D/manufacturing expenditure. These sub-classes of indicators will have an impact on one or several of four general dimensions: 1) creation and application of new knowledge; 2) human resources; 3) finance and funding; and 4) commercialization.

4.1.1 Patents and scientific publications as S&T output indicators

Patents and publications are useful output indicators of R&D activity and allow for comparison across countries. Number of scientific publications has been used to measure the output of R&D, and more particularly of scientific activities, while patents are useful for measuring the creation and application of new knowledge and are a good indicator of innovative capability (Ramani and de Looze 2002; Tijssen *et al.* 2002). Data on patent applications or scientific publications are readily available from various databases making these indicators easily measurable both nationally and internationally. The main drawback to bibliometric indicators is that they are relatively costly to acquire.

4.1.2 Personnel in private and public sectors as indicators of R&D activities

Human resources are an important dimension of the level of R&D in specific countries. The number of people involved in R&D is a direct measure of the level of R&D activity and thus of innovation potential. Human resources and their impact on innovation can be measured using several different indicators. The number of graduates and numbers of the population with tertiary education are often used to evaluate the availability of specialized workers within a country.

4.1.3 Private and public investment, financing, and R&D/manufacturing expenditures as a measure of innovation in S&T

R&D funding is an indicator of indirect investment in research and is also an indicator of how much research is being performed. However, level of spending is not a direct indicator of the level of results achieved by R&D. Funding has traditionally been used as the primary input indicator for R&D. The major advantage of taking expenditure data as a primary indicator is that the data are easily understandable, available for most countries, and are usually gathered on a regular basis. Furthermore, the money spent on research can be measured in the same unit, dollars, which makes comparison between countries straightforward. However, it should be remembered that the level of funding is not always a good indication of the long term results of R&D (commercialization), but rather is correlated with the level of research being performed in a particular country (creation of knowledge).

4.2 Insights from the OECD and the EU in the measurement of biotechnology

According to the European Commission, biotechnology is expected to offer enormous opportunity for improving quality of life through the creation of highly skilled jobs, and greater competitiveness and economic growth, and to provide new tools to address a variety of challenges such as protecting the environment. Since the recognition in recent years that the biotechnology sector is an important source of economic growth, more efforts have been put in place to measure the level of innovation in the biotechnology sector. However, developing indicators for biotechnology presents numerous challenges, partly because biotechnology is a process rather than a product and also because, until very recently, there was no international statistical definition of biotechnology. Attempts to construct scoreboards on biotechnology innovation have been mainly restricted to the European Commission and the OECD. It is significant, though, that no scoreboard for biotechnology is published on a regular basis. The OECD has on two occasions published a compendium of existing national statistics in biotechnology (OECD 2001a; OECD 2003a)

The OECD's Biotechnology Statistics Framework (OECD 2001b) divides biotechnology indicators into four main fields defined by the needs of users from government, industry, and universities. The four fields include indicators for 1) the development of biotechnology, 2) the application and use of biotechnology, 3) economic impacts, and 4) social issues, including the impact of biotechnology on health and the environment (the public benefits), and public perceptions of biotechnology. However, it is necessary to contrast the data that is used by the OECD with this idealized model of statistical indicators that would be acceptable if real world constraints such as cost, data availability and comparability did not exist. The data collected by the OECD (2003a) for biotechnology comprise five main types of indicators:

1. **Publicly funded biotechnology R&D** as a percentage of publicly funded R&D (13 countries);

2. **Dedicated biotechnology firms:** I) per million inhabitants (16 countries); II) per million GDP USD PPP (16 countries); III) country shares of dedicated biotechnology firms by technological fields (6 countries);
3. **Patents:** Ia) number of biotechnology patents granted by the USPTO, Ib) share of USPTO biotechnology patents, Ic) average annual growth of USPTO biotechnology patents granted, 1d) USPTO biotechnology patents granted specialization index; IIa) number of EPO biotechnology patent applications, IIb) share of EPO biotechnology patents applications, and IIc) average annual growth of EPO biotechnology patent applications, IId) EPO biotechnology patents application specialization index;
4. **Biotechnology venture capital investment:** I) shares in 2001 (20 countries); II) per million units of GDP (20 countries);
5. **Genetically engineered crops**, in millions of hectares (9 countries).

The data collected by the OECD are very incomplete – in fact, the only data available for every country are patent data. Other data are compiled from heterogeneous sources and therefore incorporate problems such as sustainability over time as well as comparability. The data collected by the OECD are so incomplete that it is impossible to derive a global estimate of national levels of performance, which renders the OECD scoreboard not very useful scoreboard.

The European Biotechnology Innovation Scoreboard (BIS) is more exhaustive, but is a one off effort and therefore cannot be used to study the evolution of the biotechnology industry. The European scoreboard defined more variables than was ultimately practical and feasible to collect. The data that were meant to appear in the BIS were fairly extensive since they were intended to cover: inputs and resources; scientific and technological outputs; collaboration and science and technology transfer; as well as information on use, outcomes and impacts of biotechnology. However, of the fourteen types of data that it was planned should be collected for the BIS, only nine types were effectively available or practical to collect, and not all data were available for every country. In addition, all the data except those on scientific publications and patents, were collected from heterogeneous sources and thus are not always comparable. The following list presents the types of data effectively collected (in bold) and those that were not available (in italics) for the BIS:

Inputs and resources:

1. **Human resources** I) PhD graduates in life sciences per capita; II) *Biotechnology employment*
2. **Dedicated biotech firms** per capita;
3. **Biotechnology venture capital** raised as % of GDP;
4. **R&D expenditures in biotechnology** I) by government as percentage of GDP; II) *by business as a percentage of GDP;*

Scientific and technological outputs:

5. **Biotechnology publications** I) per capita; II) citations per publications;
6. **Patents:** I) number of biotechnology patents granted by the USPTO per capita; IIa) number of EPO biotechnology patent applications per capita.

Collaboration and science and technology transfer

7. *University spin-offs;*
8. *Alliances: I) Collaborative research agreements PSRO-industry; II) alliances between large firms and dedicated biotech firms;*
9. *Joint scientific publications between PSROs and industry (also an output indicator using publications);*
10. *Joint EPO patents applications between PSROs and industry (also an output indicator using patents);*

Use of biotechnology, outcomes and socioeconomic impacts

11. **Drug approvals** per capita;
12. **Field trials in genetically modified organism crops;**
13. **Public understanding of biotechnology.**
14. *Biotechnology revenues;*

The BIS is the European Commission's first attempt to measure the main drivers of innovation in the area of biotechnology. One of the difficulties of constructing this scoreboard was the lack of publicly available and comparable data in the countries of the European Union due to the fact that biotechnology does not yet appear in official statistical classification schemes. A unified definition of the term biotechnology was recently agreed upon and should help to identify more clearly indicators for the European Union, and render comparisons between countries easier.

The experience of the OECD and the European Commission show that it is much easier to define indicators than to find appropriate data to construct and update a scoreboard on a regular basis. Their experience also demonstrates that data are often incomplete in the sense that they are not available for every country, and are not always immediately comparable due to the heterogeneity of their sources, which means that care must be taken in comparing between countries.

5 Elements of a Canadian Biotechnology Scoreboard

Science-Metrix mandate for this study was to provide the skeleton of a scoreboard designed to *measure innovation performance*. As such, the scoreboard is not designed to provide information on key aspects of Industry Canada's or CBS's missions which, in addition to spurring innovation in the Canadian biotechnology industry, also aim to improve quality of life for Canadians and support sustainability. Measuring these aspects seems to be the only way to guarantee that the Canadian Government is not only an instrument of industrial development, but also an institution that strives for the betterment of the social condition in Canada. Sustainable development is an objective that must be pursued to guarantee that future generations have good quality of life and a clean and healthy environment in the context of an ever more competitive industrial structure. Steps towards sustainable development and a clean environment also need to be measured. It is strongly recommended that Industry Canada and the Canadian Biotechnology Advisory Committee address these issues and investigate how a scoreboard that is not limited to measuring innovation performance could monitor developments in these areas.

Based on the review of the literature on the experience of Europe and the OECD, Science-Metrix suggests constructing a scoreboard that would use the following indicators:

Human resources

- **R&D workforce in industry, government and universities.** Currently, we have data on numbers of researchers in industry, but no inventory of R&D resources in government and universities has been made, and the literature is insistent that they also play a role.
- **Number of employees overall.** Although this statistic is currently collected at the Canadian level, it is not available systematically in other countries.

Companies

- **Number of DBFs.** These data are collected regularly by statistics Canada through the BUDS. Data are available at the international level although comparability is an issue due to a lack of a common definition.

Financial variables

- **R&D spending in industry, government and universities.** Currently, we have data on R&D spending in industry. Data on R&D spending by government are available at the international level. R&D spending in biotechnology in universities is virtually non-existent.
- **Venture Capital.** Currently, statistics on VC are readily available, although some care is needed because the definition of biotechnology varies considerably between North America and Europe.
- **Value of publicly traded biotechnology companies.** Although this value is seldom used, it would provide a robust indicator of the capacity of the industry to raise money through IPO and the issuing of shares. A bull market is a clear indication that it is becoming easier to raise money. Conversely, IPOs are seldom made in periods of bear markets. It would be interesting to study the correlation between the stock market and venture capital availability, which is likely to

be high. The advantage of using stock market data is their wide ranging availability across countries, which enhances international comparability.

- **Company revenues.** These data are collected in Canada in the BUDS, but its availability in other countries varies greatly.
- **Size of the local market, imports and exports.** Obtaining data on the size of the national market would provide valuable information about the uptake of biotechnology. Import and export data, as well as balance of trade data would add to our knowledge of the role played by biotechnology in national wealth building. Statistics Canada, which currently gathers statistics on trade, should be pressed to modernize its categories to account for fields that have emerged during the last fifty years including biotechnology.

Scientific and technological outputs

- **Number of scientific publications, citations per publication.** The literature is insistent that scientific performance is an essential contributor to performance in biotechnology. In addition, scientometric data present a great advantage from the point of view that the same method could be applied to measuring the outputs of every country and, consequently, it is one of the most robust ways to compare the performance of various countries.
- **Number of patents granted by the USPTO; applications for patents to the EPO; triadic patent families.** The protection of IP is a determining factor not only in securing markets, but also in terms of the ability of companies to raise VC as well as their capacity to achieve stock market listing. Similar to scientometric data, technometric data are inherently comparable across countries.
- **Collaboration between sectors.** Scientific publications are inherently powerful indicators for the measurement of collaboration because of co-authorship. Links between sectors (university-industry; university-government; industry-government; university-industry-government) can be studied fairly easily using scientometric methods. The only drawback is that each institution that appears in a paper must have its sector coded which means that there are limits to international comparability because of the huge amount of work that is involved in coding all the institutions that contribute to biotechnology science.

These are the main indicators that could be considered to produce a Canadian biotechnology scoreboard. Many of these data are readily available; others would require that government agencies update their classification systems. For instance, there are no data on biotechnology trade. These data would really contribute to our understanding of whether and how biotechnology contributes to national wealth building.

A number of the indicators examined in Section 3.2 did not make it to the final scoreboard. Although it would be interesting to evaluate dimensions such as policy choice, mobility and entrepreneurship, they were deemed either too costly and/or too contentious to measure. For instance, measuring entrepreneurship would most probably involve a qualitative assessment of each country's situation through a survey of its national experts. Even if the results obtained were reliable, they still might not indicate the level of entrepreneurship in a country. In addition, it is yet to be demonstrated that entrepreneurship is an essential and unique way of transferring knowledge from academia to the industry. Also, since the objective of measures to promote entrepreneurialism or incubators is to increase the number of DBFs and enhance their performance, measures of these

latter dimensions would implicitly include the former. Also, in the context of limited resources, measuring the CRO sector does not appear essential.

The limited availability of high quality and comparable data, the limited measurement possibilities of some dimensions, and the shortcomings of the current state of knowledge on innovation greatly restrict the range of indicators that can be used. The indicators included in the resultant scoreboard, therefore, are similar to those used by the OECD and the EC.

The experience of the OECD and the EC shows that however basic the choice of indicators, international benchmarking using scoreboards is severely limited by data availability. However, our work differs in relating the choice of indicators to the theory.

It is suggested that a Canadian biotechnology scoreboard should comprise two parts: one that would present mostly Canadian data and would use time-series to examine how the industry is evolving; and one that would use data that are broadly comparable across countries, and that would allow decision makers to determine how well Canada is doing in the field compared to other countries. Although the ideal would be a very detailed and complete scoreboard, the limited availability of indicators forces some realism about what can be expected from such an instrument. Statistics Canada is already fulfilling a great need with its BUDS, but the results of these surveys need to be published more quickly. Typically it is two years before the data are published in their entirety. A large part of the data needed to build a good scoreboard is already being collected by Statistics Canada. These data now have to be made available, assembled in time series and completed by data on scientific output, IP and financing to set the performance of the Canadian biotechnology industry in the international context.

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Appendix

Table I Main dimensions and indicators used by the OECD and the European Commission in general S&T scoreboards

LEGEND:

bold: European Commission S&T indicators	Primary dimension:	x
<i>italic: OECD S&T indicators</i>	Secondary dimension:	
BERD: Expenditure on R&D in the Business Enterprise Sector FTE: Full Time Equivalent on R&D GBAORD: Government Budget Appropriations or Outlays for R&D GERD: Gross Domestic Expenditure on R&D GOVERD Government Intramural Expenditure on R&D GUF: General University Funds HERD: Expenditure on R&D in the Higher Education Sector R&D: Research and Experimental Development GDP: Gross Domestic Product PPP: Purchasing Power Parities		

Indicators	DIMENSIONS				PATENTS/PUBLICATIONS
	Creation / Application of Knowledge	Human Resources	Finance/ Funding	Commercialization	
EPO high-tech patent applications	x				
USPTO high-tech patent applications	x				
EPO patent applications	x				
USPTO patents granted	x				
Scientific publications	x				
<i>Number of triadic patent families</i>	x				
<i>Number of patents applications to the EPO</i>	x				
<i>Number of patents granted by the USPTO</i>	x				
<i>Share of countries in triadic patent families</i>	x				
<i>Number of patents in the ICT sector-applications to the EPO</i>	x				
<i>Number of patents in the ICT sector-grants at the USPTO</i>	x				
<i>Number of patents in the biotechnology sector-applications to the EPO</i>	x				
<i>Number of patents in the biotechnology sector-grants at the USPTO</i>	x				

LEGEND:

bold: European Commission S&T indicators	Primary dimension:	x
<i>italic: OECD S&T indicators</i>	Secondary dimension:	

Indicators	DIMENSIONS				
	Creation / Application of Knowledge	Human Resources	Finance/ Funding	Commercialization	
S&E graduates		x			PERSONNEL PRIVATE AND PUBLIC SECTORS
Population with tertiary education		x			
Participation in life-long learning		x			
Employment in medium-high and high-tech manufacturing		x			
Employment in high-tech services		x			
<i>Total researchers (FTE)</i>		x			
<i>Total researchers-compound annual growth rate</i>		x			
<i>Total researchers per thousand total employment</i>		x			
<i>Total researchers per thousand labour force</i>		x			
<i>Total R&D personnel (FTE)</i>		x			
<i>Total R&D personnel-compound annual growth rate</i>		x			
<i>Total R&D personnel per thousand employment</i>		x			
<i>Total R&D personnel per thousand labour force</i>		x			
<i>Total researchers (headcount)</i>		x			
<i>Women researchers (headcount)</i>		x			
<i>Women researchers as a percentage of total researchers (headcount)</i>		x			
<i>Business enterprise sector: total researchers (headcount)</i>		x			
<i>Business enterprise sector: women researchers (headcount)</i>		x			
<i>Business enterprise sector: women as a % of total researchers (headcount)</i>		x			
<i>Government sector: total researchers (headcount)</i>		x			
<i>Government sector: woman researchers (headcount)</i>		x			
<i>Government sector: woman researchers as a % of total researchers (headcount)</i>		x			
<i>Higher education sector: total researchers (headcount)</i>		x			
<i>Higher education sector: woman researchers (headcount)</i>		x			
<i>Higher education sector: woman as a % of total researchers (headcount)</i>		x			
<i>Business enterprise researchers (FTE)</i>		x			
<i>Business enterprise researchers-compound annual growth rate</i>		x			
<i>Business enterprise researchers as a percentage of national total</i>		x			
<i>Business enterprise researchers per thousand employment in industry</i>		x			
<i>Total business enterprise R&D personnel (FTE)</i>		x			
<i>Total business enterprise R&D personnel - compound annual growth rate</i>		x			
<i>Total business enterprise R&D personnel as a percentage of national total</i>		x			
<i>Total business enterprise R&D personnel per thousand employment in industry</i>		x			
<i>Higher education researchers (FTE)</i>		x			
<i>Higher education researchers-compound annual growth rate</i>		x			
<i>Higher education researchers as a percentage of national total</i>		x			
<i>Higher education total R&D personnel (FTE)</i>		x			
<i>Higher education total R&D personnel - compound annual growth rate</i>		x			
<i>Government researchers (FTE)</i>		x			
<i>Government researchers - compound annual growth rate</i>		x			
<i>Government researchers as a percentage of national total</i>		x			
<i>Government total R&D personnel (FTE)</i>		x			
<i>Government total R&D personnel - compound annual growth rate</i>		x			

LEGEND:

bold: European Commission S&T indicators	Primary dimension:	x
<i>italic: OECD S&T indicators</i>	Secondary dimension:	

Indicators	DIMENSIONS			
	Creation / Application of Knowledge	Human Resources	Finance/ Funding	Commer- cialization
Public R&D expenditures			x	
Business expenditures on R&D (BERD)			x	
Share of high-tech venture capital investment			x	
Share of early-stage venture capital in GDP			x	
Sales of 'new to market' products in manufacturing			x	
Sales of 'new to market' products in services			x	
Sales of 'new to the firm but not new to the market' products in manufacturing			x	
Sales of 'new to the firm but not new to the market' products in services			x	
Internet access/use			x	
ICT expenditures			x	
Share of manufacturing value-added in high-tech sectors			x	
Volatility rates of SMEs in manufacturing			x	
Volatility rates of SMEs in services			x	
<i>Gross domestic expenditure on R&D (GERD)</i>			x	
<i>GERD as percentage of GDP</i>			x	
<i>GERD-compound annual growth rate</i>			x	
<i>GERD per capita population</i>			x	
<i>Civil GERD as a percentage of GDP</i>			x	
<i>Basic research expenditure as a percentage of GDP</i>			x	
<i>Industry-financed GERD as a percentage of GDP</i>			x	
<i>Government-financed GERD as a percentage of GDP</i>			x	
<i>Percentage of GERD financed by industry</i>			x	
<i>Percentage of GERD financed by government</i>			x	
<i>Percentage of GERD financed by other national sources</i>			x	
<i>Percentage of GERD financed by abroad</i>			x	
<i>Percentage of GERD performed by the Business enterprise sector</i>			x	
<i>Percentage of GERD performed by the higher education sector</i>			x	
<i>Percentage of GERD performed by the government sector</i>			x	
<i>Percentage of GERD performed by the private non-profit sector</i>			x	
BERD			x	
<i>BERD as a percentage of GDP</i>			x	
<i>BERD - compound annual growth rate</i>			x	
<i>BERD as a percentage of value added in industry</i>			x	
<i>Industry-financed BERD</i>			x	
<i>Industry-financed BERD-compound annual growth rate</i>			x	
<i>Industry-financed BERD as a percentage of value added in industry</i>			x	
<i>Percentage of BERD financed by industry</i>			x	
<i>Percentage of BERD financed by government</i>			x	
<i>Percentage of BERD financed by other national sources</i>			x	
<i>Percentage of BERD financed by abroad</i>			x	
<i>BERD performed in the aerospace industry</i>			x	
<i>BERD performed in the electronic industry</i>			x	
<i>BERD performed in the office machinery and computer industry</i>			x	
<i>BERD performed in the pharmaceutical industry</i>			x	
<i>BERD performed in the instruments industry</i>			x	
<i>BERD performed in service industries</i>			x	
<i>Percentage of BERD performed in the aerospace industry</i>			x	
<i>Percentage of BERD performed in the electronic industry</i>			x	
<i>Percentage of BERD performed in the office machinery and computer industry</i>			x	
<i>Percentage of BERD performed in the pharmaceutical industry</i>			x	
<i>Percentage of BERD performed in the instruments industry</i>			x	
<i>Percentage of BERD performed in service industries</i>			x	

PRIVATE AND PUBLIC INVESTMENT, FINANCING, AND R&D/MANUFACTURING EXPENDITURES

LEGEND:

bold: European Commission S&T indicators	Primary dimension:	x
<i>italic: OECD S&T indicators</i>	Secondary dimension:	

Indicators	DIMENSIONS				
	Creation / Application of Knowledge	Human Resources	Finance/ Funding	Commercialization	
<i>Higher education expenditure on R&D (HERD)</i>			x		PRIVATE AND PUBLIC INVESTMENT, FINANCING, AND R&D/MANUFACTURING EXPENDITURES
<i>HERD as a percentage of GDP</i>			x		
<i>HERD-compound annual growth rate</i>			x		
<i>Percentage of HERD financed by industry</i>			x		
<i>Government intramural expenditure on R&D-GOVERD</i>			x		
<i>GOVERD</i>			x		
<i>GOVERD as a percentage of GDP</i>			x		
<i>GOVERD - compound annual growth rate</i>			x		
<i>Percentage of GOVERD financed by industry</i>			x		
<i>Total government budget appropriations or outlays for R&D - GBAORD</i>			x		
<i>Defence budget R&D as a percentage of total GBAORD</i>			x		
<i>Civil budget R&D as a percentage of total GBAORD</i>			x		
<i>Civil GBAORD for economic development programmes</i>			x		
<i>Civil GBAORD for health and environment programmes</i>			x		
<i>Civil GBAORD for space programmes</i>			x		
<i>Civil GBAORD for non-oriented research programmes</i>			x		
<i>Civil GBAORD for general university funds</i>			x		
<i>Economic development programmes as a percentage of civil GBAORD</i>			x		
<i>Health and environment programmes as a percentage of civil GBAORD</i>			x		
<i>Space programmes as a percentage of civil GBAORD</i>			x		
<i>Non-oriented research programmes</i>			x		
<i>General university funds (GUF) as a percentage of civil GBAORD</i>			x		
<i>R&D expenditures of foreign affiliates</i>			x		
<i>R&D expenditures of foreign affiliates as a % of R&D expenditures of enterprises</i>			x		
<i>Technology balance and payments: receipts</i>			x		
<i>Technology balance and payments: payments</i>			x		
<i>Technology balance and payments: payments as percentage of GERD</i>			x		
<i>Total exports: aerospace industry</i>			x		
<i>Total exports: electronic industry</i>			x		
<i>Total exports: office machinery and computer industry</i>			x		
<i>Total exports: pharmaceutical industry</i>			x		
<i>Total exports: instrument industry</i>			x		
<i>Total imports: aerospace industry</i>			x		
<i>Total imports: electronic industry</i>			x		
<i>Total imports: office machinery and computer industry</i>			x		
<i>Total imports: pharmaceutical industry</i>			x		
<i>Total imports: instrument industry</i>			x		
<i>Export market share: aerospace industry</i>			x		
<i>Export market share: electronic industry</i>			x		
<i>Export market share: office machinery and computer industry</i>			x		
<i>Export market share: pharmaceutical industry</i>			x		
<i>Export market share: instruments industry</i>			x		
SMEs innovating in house in manufacturing					
SMEs innovating in house in services					
SMEs involved in innovation cooperation in manufacturing					
SMEs involved in innovation cooperation in services					
Innovation expenditures in manufacturing					
Innovation expenditures in services					