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BENCHMARKING INDICATORS OF INNOVATION: THEORY AND BEST PRACTICES

Marie Lavoie, York University

Working Paper 2007-04

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Abstract

Innovation plays an increasingly strategic role in economic growth and firm performance. Even though many efforts have recently been made to develop indicators, measuring innovation remains a difficult, if not impossible, task. The fact is that the sources of innovation are numerous and vary from one sector to another and from one country to another. A large body of literature in economics, business management and management of technology has explored the potential of input and output indicators to reflect different aspects and stages of the innovation process, whether at the firm, industrial, national, and international levels. The paper begins with a few reflections on the concept of innovation and technology in different theoretical economics traditions at the macro, sectoral and micro levels. The most commonly used indicators as well as those newly developed are pointed out, along with a mention of their respective strengths and weaknesses. What can be concluded for now is that there is no sole, unique indicator enabling us to better understand the reality of innovation. The challenge is to better understand the dynamics of innovation. Too often, indicators depict a static image of a phenomenon, but technology changes and a solid understanding of how technology progresses or stagnates is required in order to design the right innovation policy. Composite indicators are valuable as a starting point for an analysis. They allow cross-national comparisons of country performance and are quite useful especially for further analytical purposes. However, they are not sufficient to understand why a country has a national performance below expectations. We propose to study innovation capacity in a more systemic way by examining the dynamics of inter-industry flows. This implies the development of a taxonomy whose aim would be to produce different scoreboards for each category of firms sharing similarities in the innovation process. This exploration should be guided by 'appreciative theorizing'.

Key words: innovation, national innovation system, measurement of innovation, benchmarking innovation

Résumé

L'innovation joue un rôle de plus en plus stratégique dans la croissance de l'économie et le rendement des entreprises. Or, malgré les nombreux efforts qui ont récemment été déployés pour mettre au point des indicateurs, il demeure difficile, voire impossible, de mesurer le degré d'innovation. La difficulté vient du fait que les sources d'innovation sont nombreuses et qu'elles varient d'un secteur à un autre et d'un pays à un autre. Une abondante littérature en économie, en gestion des affaires et en gestion de la technologie est consacrée à la mesure dans laquelle les indicateurs des intrants et des extrants peuvent révéler les dimensions et les stades du processus d'innovation, à l'échelle de l'entreprise, de l'industrie, du pays et du monde. Le document débute par quelques réflexions sur les concepts de l'innovation et de la technologie selon différentes théories économiques classiques aux niveaux macro, micro et sectoriel. On y décrit les indicateurs les plus courants et les plus récents, ainsi que les points forts et les points faibles de chacun. L'unique conclusion que l'on puisse tirer pour le moment est qu'aucun indicateur ne peut à lui seul nous permettre de mieux comprendre la réalité de l'innovation. Le défi consiste donc à mieux comprendre la dynamique de l'innovation. Trop souvent, les indicateurs nous renvoient une image statique d’un phénomène, mais comme la technologie évolue, il faut bien saisir la façon dont la technologie progresse ou stagne pour concevoir la politique d’innovation appropriée. Les indicateurs composites constituent un intéressant point de départ à l’analyse. Ils donnent lieu à des comparaisons transnationales du rendement d’un pays et sont très utiles pour pousser l’analyse. Toutefois, ils n’expliquent pas à eux seuls les raisons pour lesquelles le rendement national d’un pays est inférieur aux attentes. Nous nous proposons d’analyser la capacité d’innover d’une façon plus systémique en examinant la dynamique des flux des biens et services entre les branches d’activité. Cela implique l’établissement d’une taxinomie dont l’objectif serait de produire des tableaux de résultats différents pour chaque catégorie d’entreprises dont le processus d’innovation aurait des points en commun. Cette exploration devra être fondée sur une théorie appréciative.

Mots clés : innovation, système national d’innovation, mesure de l’innovation, analyse comparative de l’innovation

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Introduction

Innovation plays an increasingly strategic role in economic growth and firm performance. The transition to a knowledge-based economy requires a solid science and technology infrastructure and capability. This transition is both the cause and consequence of globalization, so that competition is extreme and all countries must retain highly-skilled workers and attract investment in science and technology. Going global also means investing in the 'fundamentals' of innovation systems. Public policies developed at the national and regional levels can become an advantage and allow certain countries to lead the race and reach high levels of economic growth. Developing appropriate public policies requires a keen understanding of the innovation context. Innovation strategy as well as science and technology policies do not take place in a vacuum but within a policy framework where other policies are involved. It is therefore essential to gain a better knowledge of the strengths and weaknesses of the innovation system. Along with detecting these strengths and weaknesses, a first step to take would be to monitor the progress of the innovation system by means of reliable indicators in order to compare Canada's position with its main competitors.

Benchmarking is not a new technique in policy advising. In fact, it is a response to the failure of theory to address and appreciate in a coherent way, the real world and its complexity (Fagerberg: undated). 'Stylized facts' are interpreted on the basis of theory, but when theory fails to address real issues, wrong policies and disappointing results can follow and be extremely detrimental to a country's competitiveness. This is the case with innovation explained from the standard economics approach. Evolutionary theory, which has been labeled 'appreciative theory', stands very close to reality and has allowed improving our understanding of the role of innovation in economic growth. Benchmarking is a significant tool of this theory.

Canada is certainly not the only country that has benchmarking innovation as a priority. The 'Lisbon strategy' was developed by the European Union to reach similar goals. This strategy involves structural reforms to re-orient the deficient EU innovative basis towards growth sectors and a more productive economy. To evaluate the progress of its member states, the European Union uses certain indicators to assess whether the targets explicitly established have been attained. In the United States, the same preoccupation led the Council on Competitiveness to develop an innovation index in order to arrive at the best strategy to sustain productivity growth and competitiveness in the long term.

An important innovation gap, which includes product and process innovation as well as commercialization of innovations, has been identified in Canada and singled out as the main cause of low labour productivity. An improved understanding of the so-called innovation gap requires the use of better measures of innovation.

This paper expresses dissatisfaction with the existing conceptualization of technological change and the lack of indicators demonstrating the role of technological change in economic and labour productivity growth. In the long term, productivity growth is of primary importance. It allows a country to compete internationally and provide its citizens with higher incomes, leading to higher living standards and good social protection. Determinants of productivity growth are numerous and interrelated, and among these factors, innovation is essential. This report presents standard – and less standard – indicators of science and technology and more generally of input and output innovation. Innovation being a process, input and output of this process must be monitored to obtain a valid international comparison. Note that interrelated factors influence innovativeness, for example, R&D spending without human capital investment would not be conducive to innovation.

Benchmarking is a first step to discovering why some countries are more innovative than others, and towards identifying the successes and failures of national innovation systems as well as developing effective policies to improve these systems. The challenge lies in knowing how to grasp its role and importance in economic growth in order to inform policy makers about best practices. Benchmarking, an exercise based on systematic comparative work, helps interpret ‘stylized facts’. However, this learning is also constrained by contextual characteristics that should be taken into account. Emulation of policies without considering the specificity of institutions can lead to disastrous results.

Although much has recently been done to develop indicators, measuring innovation remains a difficult if not impossible task. The reality is that the sources of innovation are numerous and vary from one sector to another and from one country to another. Along with this, innovation activities are not confined to generating ideas or what is called invention; they also involve being able to reach markets. Therefore, it is possible for some countries to be at the frontier of technology without being innovators. Measuring innovation performance is also a difficult task as the spillover effect of science and technology investment can be broad (even international), can affect many sectors, and can take a long time before results are manifested.

Furthermore, the technological and scientific reality evolves quite rapidly. While it is possible to monitor the evolution of the manufacturing sector on the basis of R&D expenditures, the service sector is pervading all industrialized economies and more relevant measures are required.

Monitoring innovation can hardly be done from a static perspective. Innovation is a process and an attempt to represent this process can be made only from a dynamic and long term perspective depending on the nature of this investment. Moreover, monitoring progress can be done at different levels: international, national, industrial, and the firm level. What is more, business specialists develop and use indicators at the firm level whereas economists tend to use indicators at the industrial, national or international level. Units of analysis differ, but indicators are somewhat similar, and some are better adapted than others to specific levels. At all levels, the most traditional indicators have been based on analyzing R&D expenditures and patent data. New composite indicators are being developed and will be introduced.

A large body of literature in economics, business management and management of technology has explored the potential of input and output indicators reflecting different aspects and stages of the innovation process, whether at the firm, industrial, national, and international level. In this report, an attempt will be made to review and analyze the consistency of some indicators. Increasingly, specialists in the field recognize that there is no unique indicator and that the most relevant ones should be combined to reveal the entire innovation reality. At the same time, composite indicators are criticized. An interesting challenge lies before us.

PART 1: THEORETICAL APPROACHES TO INNOVATION

The paper begins with a few reflections on the concept of innovation and technology in different theoretical economics traditions at the macro, sectoral and micro levels. From this discussion, it will become possible to ascertain the role economists have determined for the innovation process and technological change in economic performance. These various theoretical strands have forced the use (and abuse) of certain indicators at the expense of others. This section will briefly describe some of the main currents in economics and will, by the same token, explain what place and role the phenomenon of innovation has been assigned within these theories.

1.1 Innovation and Growth

As an important introductory note, it would be worth mentioning that even though innovation is not a new phenomenon, it has attracted very little scholarly notice. Apart from Schumpeter and recent economic historians such as Gerschenkron, Rosenberg, Abramovitz as well as earlier classical economists such as Adam Smith, who recognized the importance of technological change, very few economists have paid adequate attention to this phenomenon. Economists preferred "to focus on factors such as capital accumulation or the working of markets, rather than on innovation" (Fagerberg: 2004).

The assumptions behind the neo-classical growth theory developed by Solow were that, first of all, there is an idealized economy with many competing firms, i.e. perfect competition. Economies of scale were ruled out. Constant returns to scale were imposed and technology was exogenous, i.e. a sort of public good freely available to everyone. The only way to increase productivity in such an economy would be to increase the amount of capital per worker. According to this theory, there is also the assumption that there are diminishing returns to this investment, so that beyond a certain level of capital per worker, it becomes unprofitable. The economy reaches a 'steady state' and labour productivity remains constant. The only source of long term productivity growth is exogenous technological change. As long as these assumptions are respected, this theory leads to the prediction that countries with different initial productivity levels will converge towards the same level and rate of productivity growth. However, the long run productivity levels of these countries will differ if these countries have different population growth rates and saving habits. This is called conditional convergence.

Conditional convergence that is largely reflected on the basis of income levels, as termed by Mankiw, Romer and Weil (1992) and Barro and Sala-i-Martin (1992), involves a control of 'conditions on' differences in steady states (Jones: 2002, 70). As explained by Jones,

> "(conditional convergence) is simply a confirmation of a result predicted by the neoclassical growth model: that countries with similar steady states will exhibit convergence. It does not mean that all countries in the world are converging to the same steady state, only that they are converging to their own steady states according to a common theoretical model" (Jones: 2002, 70)

The catch-up approach influenced by Gerschenkron's hypothesis, according to which backward countries tend to grow faster than rich countries, mainly due to technology transfer, has been challenged by the recognition that technology is indeed not a public good and therefore not a global public good. This new assumption has many adverse consequences for the prospects of technological catch-up. Technology is not free and available to everyone everywhere. It first requires an appropriability capacity or absorptive capacity (Cohen, Levinthal: 1990) to assimilate technological knowledge and secondly, the right institutions.

Based on the neoclassical theory of growth, empirical growth economists attempted to calculate the contribution of factor accumulation to growth of GDP and productivity. The first exercises carried out in 'growth accounting' showed that only a small part of actual growth could be attributed to capital or labour growth, leaving 80 percent of this growth unexplained or, as the theory suggested, explained on the basis of exogenous technological change. These results were quite embarrassing and many attempts were made to reduce the residual by taking additional factors into account. Adding these factors led to contradicting the assumptions of the growth accounting theory to a certain degree, and so some economists looked for a new theory. Richard Nelson and Paul Romer were amongst them, though they constructed quite different alternative theories. The former contributed to the development of the evolutionary theory while the latter was led to the development of the new growth theory.

In fact, about two decades ago, economic theories changed dramatically and the concept of innovation acquired its 'lettres de noblesse'. This was mainly due to the failure of the standard equilibrium approach to explain economic growth. Since then, the field of applied growth research has been in a state of flux and many new theories have been developed by adding measures of innovativeness. While there has been a tangible improvement in the theoretical foundations, much remains to be understood and only the best proxies of technological change and innovation will make this possible.

In the 1990s, a new strand of growth models was developed, the so-called 'new growth theory'. By introducing evolutionary reasoning to equilibrium theory, it emphasized two important mechanisms of growth: learning and R&D investments. However this theory is very different from the evolutionary one. In the first place, it is still based on the orthodox view of the economy and of agents as rational and profit maximizing. In short, this strand of growth model added two new aspects to the old neo-classical theory. First of all, technological change was endogenized and economies of scale were allowed as an assumption.

Evolutionary economics, especially the Nelson-Winter approach, looks at firms' behaviour and routines to explain innovation. In contrast to the 'New Growth Theory', evolutionary economics downplays the public good character of scientific and technological knowledge. The first argument of this theory is that without innovation, the economy will settle into a state of little or no growth (Fagerberg: 2004). The second argument relates to regularities in the process of change and therefore the central role of learning as a sequence of imitation and innovation.

One important characteristic of innovation that has been strongly emphasized by evolutionary economics is that it is not a random phenomenon. This says that what a firm or a country did in the past will influence and therefore indicate much for the future as a predictor of innovative behaviour either at the firm or national level.

Evolutionary economics is based on Schumpeter's reasoning, which has as its core a dynamic vision driven by technological competition among firms. His type of competition is of course in contrast to price competition as taught in standard textbooks. Approaches explaining cross-country differences in growth performance or with a strong evolutionary flavour have become extremely popular in recent years.

Technology in standard economics is a public good. It is important to distinguish this statement from the Schumpeterian tradition since indicators of innovation have been influenced by this tradition. For Schumpeter, innovation is not only a matter of new products or new processes but also includes a new source of supply, a new form of organization (OECD/Eurostat: 2005). The role of technology in economic change is therefore central but not unique. The fact that Schumpeter did not share the perfect competition approach and did not see technology as a public good had a great impact on his understanding of the role of diffusion on growth and competitiveness.

Is there any evidence that economic growth is a non-steady state process as is claimed in the evolutionary hypothesis of economic growth? The problem now is to develop adequate indicators that can represent innovation and technological change in particular.

1.2 Industrial Dynamics

A great number of scholars inspired by the Nelson-Winter approach explored technological regimes associated with different industries. In other words, they looked at the diversity of industries and sectors in terms of their internal dynamics. Since they found that factors influencing innovation differ across industries, their findings are quite important from a policy point of view. In fact, policy makers pay considerable attention to these differences and design policies accordingly, since the same policies and programs are not likely to work in different industries (Fagerberg: 2004).

Inspired by this latter approach, many scholars have been working on the systemic nature of innovation. This has led to exploring the sectoral and industrial characteristics of innovation. On the basis of empirical research, they have found considerable differences across industrial sectors. Among other scholars, Pavitt (1984, 1987) was convinced that seeing R&D as the only mechanism of innovation could lead to overlooking or even ignoring innovation activities coming from other sources such as learning-by-doing, by interacting, production engineering, design, etc. To confirm his assumptions, he developed a taxonomy explaining sectoral patterns of technological change.

One of the striking facts about innovation is its diversity. Over time and across industrial sectors, innovations have taken place in various ways. Hence, it becomes fundamental to understand industrial dynamics, as innovations tend to cluster in certain industrial sectors, in certain areas and time periods. Apart from this diversity, there are strong regularities. It is therefore extremely important to pinpoint these regularities as they will determine the shape of policy decisions. An important point that Pavitt (1984) emphasized concerns the impact of the variety of patterns of technical change on the generalizations analysts are often tempted to make. These generalizations are likely to be erroneous if they do not take into account the varied nature of these patterns. This is in line with Fagerberg's systemic-ness of a country according to which, in a specific economic system, innovation activities are characterized by specific relationships between firms, customers, suppliers and institutions. Moreover, Pavitt (1984) mentions the importance of technology conditions (appropriability and opportunities) as well as market conditions, in order to understand the patterns of innovation in sectors and takes these conditions into account in his taxonomy. This reasoning is also in line with Ab Iorwerth's conclusions that industry characteristics (market size and growth in demand, technological opportunity and appropriability differences) are more important empirically for R&D intensity than more general issues such as degree of concentration and firm size (Ab Iorwerth: 2005).

1.3 Innovation in Business Management

Innovation has been studied by different disciplines. Economics looked at innovation from the resources allocation perspective leaving aside the study of the innovation *process* to other disciplines, that is, the transformation of inputs into outputs. This process or what has been termed 'black box', has generally been studied by scholars from the management discipline. As innovations are chiefly located within firms, these scholars became actively involved in the study of innovation and were able to explore the dynamic and systemic nature of innovation. From this perspective, and especially the branch influenced by Schumpeter and thereby, by the evolutionary tradition, the focus was on the study of innovation projects at the firm level and on the role of the entrepreneur. According to management of technology (MOT) specialists influenced by the evolutionary logic, innovation is a very risky enterprise that requires the vision and leadership of an entrepreneur in contrast to the homogenous and unitary style of the standard management literature. Innovation is considered as a new combination of existing ideas, skills and resources resulting from a learning process not only within a firm but more generally in networks in which interaction between different actors allows the innovation to occur. In other words, firms are not closed systems and even large firms are increasingly dependent on external resources in their innovative activity.

At the firm level, innovative firms follow a path-dependent strategy in which some firms risk being 'locked-in', since switching paths can be extremely costly. Nevertheless, the growing complexity of knowledge forces firms to develop a strong capacity to absorb this knowledge. Yet the knowledge developed in firms follows a routinistic behaviour. Typically, routines differ across firms. Their knowledge bases are built incrementally and, as a result, follow a more or less unique technological trajectory. In order to grasp the evolution of these firms' technological trajectories it would therefore be possible to use indicators such as patents, and sketch the direction of their trajectory over time. Furthermore, it would be possible to predict in which directions firms should grow and diversify. This is in line with the fact that technology is cumulative. Firms are being innovative in restricted areas that are determined by their principal activities, technological conditions – opportunities and appropriability capacity – and market conditions – commercial need, size of the market — surrounding them. This follows Pavitt's logic which can be read as follows, "Since patterns of innovation [at the firm and national levels] are cumulative, its technological trajectories will be largely determined by what has been done in the past…by its principal activities. Different principal activities generate different technological trajectories. These different trajectories can in turn be explained by sectoral differences in three characteristics: sources of technology, users' needs, and means of appropriating benefits." (Pavitt: 1984, 353)

The conditions of commercialization have also been the focus of attention in this business management area. Research has been founded on the study of specific innovation projects in firms. To be sure, as explained above, this is the evolutionary theory influenced by Schumpeter's work which has initiated such research in management theory.

From this first section, we can now say that the interpretation of innovation events on a basis of a specific theoretical framework determines the choice of indicators used to represent and understand innovation activities. Thus, we can conclude that each strand of theory emphasizes different mechanisms of growth and, thereby, different indicators. While, for many reasons, investments in R&D have been the most utilized and along with them, because of their availability and quantitative nature, a great number of mechanisms are used as sources of innovation and are as important as R&D. Here, the relationships between different actors involved in the innovation system, that is, suppliers, customers and users, can certainly be mentioned.

PART II: INDICATORS

Indicators of innovation, standard and less standard, will be described in this second part of the report. As innovation is a process, it is useful to present these indicators in two main categories: inputs and outputs. This will allow us to briefly introduce major strengths and weaknesses generally associated with these indicators. Then, a third category focusing on certain composite indicators will be introduced. The development of these indicators aims at responding to the criticisms directed towards indicators with a unique index. In the third part, we will go a step further and determine at which level – aggregate, sectoral or firm – each of these indicators performs best.

2.1 Input Indicators

Knowledge and innovation are difficult concepts to measure (Hamdani: 2003, 297) and have been further constrained by the lack of data. While knowledge is surely an important source of innovation, how, however, do we measure the contribution of knowledge to innovation? Sources of innovation are varied. We know that human resources involved in the process of innovation are the main vehicles of knowledge. Knowledge accumulates in individuals through formal, non-formal and informal activities so that there is no single perfect or best measure of knowledge accumulation contributing to innovation[1].

The main activities allowing science and technological knowledge to accumulate are research and development activities, formal education and training. These will be reviewed in the following section and the indicators developed to reflect the incidence and intensity of these activities will be reported.

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[1] "Non-formal learning" means learning that takes place outside systems of formal education and training. This learning has two main components. One is the unplanned learning that occurs at work and in the home, etc. Another is the planned learning offered at work or in other activities but not recognized within the setting of formal education and training systems. Non-formal learning covers a broader field of activities than informal learning (Cedefop: 2000). "Formal training" is defined as training that has predefined objectives, a structured format, and a defined curriculum (off-the-job-training). "Informal training" is unstructured training often delivered by a colleague or supervisor (on-the-job-training) (Betcherman et al: 1997).

2.1.1 Research and Development Expenditures

Expenditures in research and development (R&D) is the single indicator that has been used consistently over time to monitor technological progress. This is not too surprising as R&D is a major form of investment. However, as explained by Patel, this indicator, "..is better at measuring technological activities in the science-based classes of technology (chemicals and electrical-electronic) than in the production-based and information-based classes (mechanical and software)" (Patel: 2000, 131). Its growing importance is due to the fact that science (especially chemistry and physics) is an important source of technological change more particularly in large firms. Obviously R&D is an input indicator and does not reflect the performance of this investment. Financial resources devoted to R&D have varied over time and across countries and some industrial sectors are much more R&D intensive than others. Although R&D is not the only source of technological knowledge, it is nevertheless an important investment (to varying degrees) in the recognition and integration of the technological development of both domestic and foreign competitors.

2.1.1.1 Research & Development: A Narrow Perspective

Limiting the measure of innovative activities to R&D would imply a very narrow perspective of the innovation process. "(…) in the post-WWII period, evidence accumulated that innovation is due not only to technology developed in R&D labs but also to overall education and training levels, production processes, engineering, design and quality control (…)" (European Commission: 2003, 40). Precise information on the nature of this process can obviously be drawn from this indicator. There can be many different kinds of R&D: civil, military, public, private, as well as fundamental and applied research. Disentangling the nature of this investment is very useful since it allows forecasting the scope of performance, the risk undertaken under such investment and the length of time it will take for such investment to be productive or not.

2.1.1.2 Trends in R&D Investment (GERD)

While looking at R&D as an input can be extremely reductive of the reality, general trends based on R&D shed some light on important issues. Using the volume of gross domestic expenditure on R&D (GERD) and R&D intensity reveals important information.

> The volume of R&D investment reflects the economy's efforts to create and accumulate new knowledge, which is essential to modern knowledge-based economies. It may also be considered as an indirect measure of a society's innovation capacity. The ability to create, disseminate and

exploit knowledge and information is increasingly crucial to the competitiveness of the economy and to higher standards of living and public health.

> R&D intensity, that is R&D expenditure (or investment) as a proportion of GDP, provides a useful measure of how much countries invest in R&D in relation to the value of their total production…it also reflects the knowledge intensity of the economies in question. R&D intensity facilitates the comparison of R&D expenditure between countries of different sizes. (European Commission: 2003, 45)

R&D intensity reveals the position of a country in comparison to others but this picture is not a simple one[2]. It is a good indicator of the knowledge intensity of these economies. Why some countries have a higher level of R&D intensity than others is complex[3]. Many factors affect the level of R&D intensity. Among the many factors that must be considered, the industrial structure is central. On the basis of this measurement, targets can be set and can serve as a guide for policy makers to launch policy measures aiming at increasing R&D investment. R&D intensity allows a comparison of R&D expenditure between countries of different sizes. As Harris (2005) pointed out, differences in R&D intensity can reflect differences in national institutions and policies to encourage R&D investment. Not only is public R&D funding targeted but also the target serves to stimulate private investment. So the following section will address the differing nature of knowledge financed either by government or the private sector.

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[2] In a recent paper published in *Research Policy*, Katz states that performance indicators based on the ratio of primary measures such as GERD /GDP should be used with caution as the denominator does not normalize as is commonly believed. Therefore, it would be impossible to make valid comparisons between innovation systems (e.g. countries or provinces). He proposes to scale adjust performance indicators in order to compare groups of different sizes. He explores scaling correlations between GERD and GDP, among others, at points in time and over time or even combining these scaling relationships over time and at points in time to construct a composite scale independent model showing how these two indicators evolved together. As discovered by Katz, ranks of countries given on the basis of conventional indicators and scale-adjusted ones can be totally different. Given the impact of these rankings on policy decisions and on perceptions of decision-makers, the development of these indicators is a very important avenue to explore in international and even national comparisons (inter-provincial) (Katz: 2006).

[3] It is worth referring to Statistics Canada's Innovation Analysis Bulletin (2004) in which they explain the un-matching GERD/GDP of Canada as compared to other countries in OECD publications. Statistics Canada adjusts and calculates the Canadian GDP differently than other countries. In fact, in Canada, the GDP is adjusted by excluding 'Financial Intermediation Services Indirectly Measured' (FISIM) that other countries do not exclude. This has the result of lowering the Canadian GDP and therefore increasing the GERD/GDP ratio.

2.1.1.3 Public vs. Private R&D

Public R&D investment directly questions the role of government. Economists will automatically take their theoretical arsenal – market failures — to justify the contribution of public research to the economy. Many vehicles can be used by the government to finance research. It is very likely that the nature of the research financed by the government will be science-related. Obviously the role of government in financing research is not only through R&D, and other means will be examined later in the paper. Criteria to justify the involvement of government relate not only to market failures but also to the wide use of the knowledge produced from this investment in the economy. Non-economic rationales are also an important motive.

The reason basic research is often the domain of the public sector is because the average size of private enterprise is too small. Moreover, basic research takes time before producing impacts and needs patient money that only the government is ready to invest. In addition to this long-term perspective such investment is risky and costly. The spillover effect of basic research is large and "the benefits of R&D, especially those of scientific research, are primarily of an indirect nature" (European Commission: 2003, 78). This appropriability problem often prevents private companies from investing in basic science.

2.1.1.4 Civil vs. Military R&D

Some researchers will insist on separating civil and defence R&D as the spillover effect of military expenditures can easily impact the civil sector and according to these researchers, there are important complementarities between these two sectors (European Commission: 2003). Others argue that the impact of these investments can be extremely different. It is certain that over time, we can find different levels of investment in these two categories for the same country. On the other hand we find, from one country to another, very different levels of investment in defence R&D. Many factors influence these levels. The end of the Cold War has reduced investment in military expenditures while more recent years have witnessed a resurgence in military industry.

Even though civil and military R&D is complementary, it is quite useful to keep the statistics apart. The first reason is that military R&D quite often aims at scientific knowledge and also because aggregate R&D patterns amongst countries present sharply differing pictures. As well, they help identify incentives behind such funds. Over time, the changing ratio between civil and defence research sheds important light on the patterns of investment.

When comparing R&D performance in Canada and in the United States, distinguishing between and civil expenditures is very important. In fact, it would be quite interesting to determine the magnitude of business opportunities military with the budget of Defence R&D for American firms as "much of the U.S. innovation system is linked to large strategic initiatives motivated by defense and security, and to health research" (Harris: 2005, 12).

2.1.1.5 Software R&D

The software industry is at the core of information technologies, which is why there is such a policy interest towards it. It is also the most rapidly growing sector. In terms of value added, employment, wages, R&D intensity, patents and investment, it is a very dynamic sector. This is why we treat this industry separately in this report.

Innovations in this industry are considerable and challenge the industrial leaders but rest on the complementarity between the evolution of hardware and software. In the last decade, the ICT sector experienced the highest growth rate in the economy. The software sector, like the rest of the ICT industry, invests heavily in R&D. Looking at R&D expenditures on software across all sectors of the economy is an important indicator as software pervades all industrial sectors. In addition, this sector contributes to economic performance throughout the entire economy by the huge array of applications. The problem is that there is a lack of official data involving a cross-country analysis (OECD: 2002). In contrast to other industries in which replication costs are very high, these costs are minimal for software while costs for development and testing are high.

2.1.2 Capex (capital expense)

Capex or investment spending in machinery and equipment (M&E) and buildings is an interesting input indicator given its complementarity with innovation expenditures especially in the manufacturing sector. Although it does not capture innovation *per se* it can somewhat proxy its intensity. According to Harris, business decisions to conduct R&D are part of the larger strategic business framework so that there are good reasons to suppose that R&D spending decisions and capex spending are related (Harris: 2005). What is more, Machinery & Equipment investment as a percentage of GDP is a good measure of potential innovation and diffusion (Gera: 2005). Gu and Tang (2003) used real investment in machinery and equipment per worker as a measure of technology adoption since M&E embody new technologies. After modeling a comprehensive measure of innovation based on the latent variable including four indicators capturing both technology generation and technology adoption, i.e. R&D, patents, technology adoption and skills, they found a positive and statistically significant impact on productivity in Canadian manufacturing sectors. This finding is very interesting given the fact that many studies did not find a strong link between R&D (when taken alone as a proxy of innovation) and productivity in Canada. This probably captures the fact that, in Canada, many firms are foreign-controlled and rely on purchased technology (Gu, Tang: 2003, 10). It is in line with what Archibugi and Coco stated about the importance of combining not only measures of generating inventions and innovations but also indicators of their application and dissemination (Archibugi, Coco: 2005, 178)

2.1.3 Investment in Knowledge

The accumulation of technology is not so much a matter of R&D investment, patenting activity, or having certain types of machines and equipment, but a rather more complicated process with knowledge and the processes of learning at its core. Learning is therefore a primary element of technological change. Linking technology to knowledge is a step towards a better understanding of the process underlying technological change. Recognizing it means knowing that skills, knowledge and education are important and implies a rising demand for highly-skilled workers and a reduced one for less skilled.

Human capital is the most fundamental ingredient of knowledge-based economies. While knowledge accumulates through different vehicles such as training, informal and non-formal learning, work experience, and R&D amongst others, education is of the essence as it allows a better absorption of future knowledge acquired through a variety of channels. Educational investment, especially in tertiary education, is therefore a good proxy of the innovation potential of a nation, assuming that similar amounts invested in education will produce similar levels of qualification in different countries.

As this report is about innovation in advanced industrial countries, special focus on tertiary education investment as a percentage of GDP is an important indicator of scientific and technological capacity. Knowledge economies have created an increasing demand for highly-skilled graduates and this will more than likely be a permanent character of these changes. Another important element in the discussion of tertiary education investment is the private nature of this investment. The question of balancing supply and demand regarding highly-skilled graduates often points to the capability of private universities to find solutions to problems of discrepancies, a capability not shared by public universities that are less flexible. It is certainly noteworthy to observe the shift in financing sources from public to private ones in tertiary education between 1995 and 1999 for Nordic countries. These countries are, in many ways, leading innovation performers. Therefore, distinguishing between private and public investment (growth and level) in tertiary education can be meaningful.

Another indicator worth examining in order to get the full picture of the financial investment in tertiary education is the output in terms of science and technology graduates as well as the number of all graduates (graduation rate). According to recent findings, there seems to be no direct correlation. Young people appear to be reluctant to enter a career in science or engineering. It is worth asking if private financing would be able to offer more attractive curricula. Universities have an important role in the new economy and must face new challenges. To respond to these new challenges, they will have to be flexible and re-orient their programs towards students' and firms' needs. So, output patterns of graduates are worth examining as the financing of higher education is an important indicator not only of quantity but also of quality.

2.1.3.1 Who Performs R&D?

The OECD Canberra Manual presents two approaches to measuring human resources in science and technology: (1) based on formal qualifications, and (2) based on occupations. Gathering these two measures is important as "…not all people with higher education in S&E fields of study enter research careers, because in today's knowledge-based and transformed economy, people with science and technology skills find that there is considerable demand for their talents from across a number of sectors and therefore enter a wide range of occupations"[4] (European Commission: 2003, 192).

Graduates in science and engineering furnish an insight into the importance accorded to science and technology in a specific country. So that graduates in science and engineering as a share of total graduates as well as the growth patterns of these graduates (in the relevant age groups) provide an appreciation of the balance of supply and demand for highly skilled R&D. The share of researchers in the labour force, that is, how many people are active in R&D relative to the total number of people is useful as it signifies the relative importance of R&D jobs in the labour market (European Commission: 2003, 181). As this share varies across different sectors and countries, a disaggregation by economic sectors offers a more accurate portrayal.

To conclude, let us say that to classify a scientist or engineer by occupation or according to the highest degree as suggested in the Canberra Manual, is not a perfect measure (National Science Foundation: 2006, 3-4). Classifying by occupation can be misleading in terms of the work a person actually does. A classification on the basis of the highest degree (the most recent) can also lead

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[4] Another explanation can be given for Canada based on our research on the National Graduates Surveys database where we found a high unemployment rate for pure science graduates (Lavoie, Finnie: 1999). This tends not only to reflect attractive peripheral occupations for graduates in this field but also a limited demand for this type of specialists in Canada in research occupations.

to some imprecision. For example, where should a person with a first degree in engineering, a second in biology be classified? Although these classifications have limitations, there is no definitive solution.

2.1.3.2 Higher Education Expenditure on R&D (HERD)

Among institutions undertaking fundamental research are universities, public research centres, hospitals, etc. Let us examine the first type of investment, which is the expenditure on R&D by the higher education sector (HERD). The higher education share of total public R&D expenditures reflects very well the structure of government spending on public research (European Commission: 2003, 81). Although the government is the major player in financing HERD, it is not the sole source of funds. The private sector as well as financing from abroad can be significant ones, depending on the country. These sources vary among countries.

2.1.3.3 Investment in Training

Training is another important channel for the accumulation of knowledge, which is why it is treated in this section. There are two indicators for measuring training – incidence and intensity. It is important to combine both indicators because in some nations, training is spread more thinly throughout the population than in others (Statistics Canada/HRDC: 2001). *Incidence* refers to the proportion of locations supporting training, as well as the proportion of individuals who receive training in a given time period. Caution is required, given the significant differences between surveys related to training definitions, countries reviewed, the nature of the surveys, years covered in the surveys, and so on. However, this exercise is useful, as it provides an international comparison of training participation. Nevertheless, incidence needs to be complemented by the measure of *intensity* — that is, a measure of the average training duration in hours and per participant.

Intensity of training refers to the breadth and depth of training — that is, the number of employees receiving training — or to the duration of training courses (Betcherman *et al*: 1997). This is an important variable, since the duration of training may vary independently of its incidence between countries and populations (O'Connell: 1999).

While there is no shortage of surveys on training, we still do not have the complete and accurate picture needed to understand the wide variety of trends at the business enterprise, national, and international levels. The IALS provides some interesting information related to training and allows an international comparison of training markets for 22 countries, using nationally representative samples of the population aged 16 to 65. While the main aim of the IALS is to generate comparable profiles of adult literacy scores, the background questionnaire made it possible for us to get information about patterns in adult education participation and training both within and between countries. First of all, it supplies information about the incidence of participation in adult education. It also provides a measure of the intensity and total training effort in the 22 countries. Despite some limitations and considering the sate of other surveys, the IALS has provided consistent information in terms of adult education and training patterns both between and within countries.

2.1.3.4 Mobility Indicators

Although not directly an input indicator of innovation, mobility patterns can provide information on the dynamic of where science and technology research takes place at certain points in time. Knowledge creation and accumulation of technology are drivers of growth and are nourished by the exchange of ideas, transfer of knowledge, and so on. Mobility of highly skilled workers and researchers is therefore an important channel of knowledge creation. Of course, it can also have a negative impact on a country’s human capital base (European Commission: 2003, 179). In any case, it is necessary to grasp the mobility patterns inside and outside a country.

Inter-industrial, inter-occupational and inter-firm mobility can reveal innovation patterns in a specific country over time. For example, longitudinal databases similar to the National Graduates Survey (NGS) carried out by Statistics Canada provide an opportunity to track graduates during their early years in the labour market including their inter-occupational, inter-firm and inter-industrial mobility. Papers published by Lavoie and Finnie (1998, 1999) on engineers and other highly-skilled workers have shown considerable diversity in mobility patterns within a country.

Furthermore, international mobility is a significant element in the reality of skilled workers and has become an important stake for national economies in the emerging global market for skills. Countries have developed strategies to lure skilled workers from overseas. Measuring and understanding the international mobility patterns of highly-skilled workers is therefore strategic for governments. As explained in the European Commission report, "While there are statistics on duration of stay from the immigration services, little or no information is available on the ‘types’ of persons visiting, in terms of their educational levels, field of training…Some immigration services also record skills, while others focus on the applicants’ planned occupations, with the result that comparative information is scarce". (EC: 2003, 241)

2.2 Output Indicators

A black box is defined by Rosenberg as the process whereby inputs are transformed into outputs. Measuring output or performance is not an easy matter, "the measurement of efficiency in R&D is one of the most complex problems in management economics" (Freeman, Soete: 1997, 112). Output indicators remain quite limited especially when aiming at international comparisons. Besides, performance is not only appraised in economic terms but technology performance is also a key aspect. However, technology performance does not necessarily lead to economic performance, while to perform economically, an invention should reach technology standards. The rate of investment in research and development has increased considerably but what has the outcome of this investment been? The problem is that measuring economic impacts of technological or scientific innovation is much more difficult than measuring resources invested in research (Guellec: 1999, 16)[5].

2.2.1 Patenting Activity: Measuring Invention

Patenting is the codification of technological knowledge in patents. Firms invest considerable time and money obtaining patent protection, thus they expect high levels of protection. However, it would be reductive to limit the patenting strategy of firms uniquely to protection. In some industrial sectors, patenting is a marketing strategy in order to show competitors that they are in the race and leaders in the field. Firms could just as well keep a policy of secrecy or use other means of appropriation in order to avoid giving information on their research strategy and direction. Although these strategies are located on a 'micro scale', it is vital to understand them to be able to interpret correctly the patenting trends at the macro and industrial levels.

Patenting activity is nevertheless an essential source of data and can potentially reveal crucial information on patterns of technological change. However, patents as indicators have considerable shortcomings. "… not all inventions are patentable, and not all patentable inventions are patented." (Tang 2003, 205). There are different national or regional patent systems. Statistically, those most used are in Europe, the US and Japan. If patents are a good indicator of invention, what they really measure is technological competencies as do scientific papers.

Care is necessary when interpreting patent data. Patents do not measure innovation *per se* but invention. According to Peeters and van Pottelberghe de la Potterie, they are a codification of an invention and might rather be the outcome

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[5] In the present report, the focus is on indicators of technological performance only. A broader literature review and analysis would be required to introduce the links between innovation inputs and economic performance.

of basic and applied research as opposed to development activities. Fundamentally as Hall *et al* suggest, "…the whole idea of patents is that they constitute a ‘package deal’ namely, the grant of temporary monopoly rights in exchange for disclosure" (Hall, et al: 2001, 4)

To undertake international comparisons, patent analyses are often based on the United States Patent and Trademark Office (USPTO). Given the size of the American market for technology within the OECD countries and as this country is still leading in science and technology, it is assumed that foreign companies look for protection in the United States. In the third European Commission report (2003, 329), three sets of indicators are analyzed (the American one, i.e. USPTO, the European one, i.e. EPO, and, the Japanese patent Office, i.e. JPO). Looking at these patent systems, we must carefully take the ‘home advantage’ into account, as firms in a country tend to patent domestically first.

Concretely, over time, patent statistics can inform us of the pace of change of a specific technology in relation to competing technologies as well as provide insight into the most dynamic patenting countries in a specific technological field. Furthermore, patent statistics can give information on research team size. Affiliation of its members is also a fascinating component because it reveals the international scope of the team having developed the invention as there is information on the geographical location of these affiliations.

2.2.1.1 Patent citations

As mentioned above, the value – technological or economic – of patents differs tremendously from one to the next. So relying exclusively on patent counts as indicators of innovative output is seriously limited. To overcome such a limitation, patent citations is a good tool and appears to be correlated to the value of innovations (Hall: 2001, 6). In fact, patent data include citations to previous patents as well as to the scientific literature. It makes it possible to assess the ‘value’ of the invention by tracing the multiple linkages between many other components such as inventors, other related inventions, firms, affiliation of inventors where the invention takes place, etc. Finally, patent citations allow the ‘spillover effect’ of a patent to be measured.

2.2.1.2 Flows of Patents

The payment or ‘royalty’ of the license is a technological output measure and captures the international flows of technology. A licence is "defined as the right on the part of one firm to make commercial use of a proprietary technology belonging to another, subject to certain agreed conditions" (Clark: 1985, 71).

There is an advantage in using licence payments as an indicator. Since they are "collected and processed as part of the normal operation of foreign exchange control", they are therefore readily available. (Clark: 1985, 72). Even if they represent technological value quite well, they must be used with great caution as a financial measure since licence fees are only one form of payment. Some suppliers receive payment through profits from joint-venture arrangements or from the sales of intermediate goods.

2.2.1.3 Revealed Technological Advantage: a Relative Specialization Index

Using patent statistics allows developing a 'revealed technological index' that makes possible a better understanding of the technological specialization of a country in relation to other countries and its evolution over time. In other words, it can inform whether a specific country maintained or lost an advantage for a specific technology over time and in relation to competitors. This index measures a country's performance in an industrial sector relative to its aggregate performance. In this way it also reflects industrial specialization and the evolution of this specialization over time in a specific country or for a specific firm. This is a useful index mimicking the Revealed Comparative Advantage. It is defined "as a country's (or a firm's) share of US patenting in a sector divided by its share of all US patenting" (Pavitt, Patel: 1989, 10).

2.2.1.4 Software patents

Patent indicators in the software industry give relevant information on the increase of software inventions. To make international comparisons, the United States patent system is the most appropriate as is the case for other technologies. However, there is a lack of precise classifications related to software patents. There is a selection of software-related classes such as computer graphics processing and data processing amongst which electronic commerce is included (under U.S. patent class 705). On the other hand, the search for software patents can be done by looking at the word 'software' included in the patent description. Both ways of looking at the number of software patents are limited but nevertheless reveal a considerable increase over the last decades.

2.2.1.5 Limitations

Clark mentions the following limitations to patent statistics: 1) although they are quantitative indices, no economic value is attached to them; 2) they tend to reflect inventive rather than innovative output; 3) international comparisons are hazardous given that patent laws vary between countries; 4) there is a huge variety of patentability amongst different inventions; 5) patenting can release important information to competitors so that the attention of potential imitators might be drawn to them. Keeping secrecy or lead time can be chosen as the best strategy; 6) and finally, patenting activities vary over time. (Clark: 1985, 70-1). Furthermore, others will add that the standard of novelty of patents and utility for granting patents is not very high and varies substantially over time and across countries (Tidd, Driver: 2000, 96).

As an indicator of innovation, patent-based indicators are therefore debatable. Besides, the importance of this protection mechanism varies across industries and is valuable especially for chemicals and pharmaceuticals (Peeters and van Pottelberghe de la Potterie: 2003, 2) resulting in an over-representation of these industrial sectors.

It should also be noted that, technically speaking, a search strategy for a product group in a patent database is complex. This strategy must be sequential and not designed once and for all. To find appropriate keywords to circumscribe and delimit the search for a product group or technology is strategic but constitutes a difficulty that can be overcome only by experts involved in the field. This is called the technometric method. Technometrics is largely based on expert interviews. Crossing these interviews using a formal arithmetical framework can improve the interpretation of the innovation process success or failure. "This method permits systematic international comparison between specifications covering new products and processes. Technometric indicators are established in direct relation to the foreign trade classifications product-wise as well as to patent statistics" (Grupp: 1994, 176).

Finally, we must emphasize that there is no match between a technology and an industrial sector as technologies can irrigate many industrial sectors. Thus, the unit of analysis of patent indicator is a technology and cannot be an industrial sector.

Despite these numerous limitations, patents are one of the most used indicators, since they are available at a detailed level of technology over a long period as is the case for R&D, are very comprehensive covering small and large firms and reflect the capacity of a firm to generate change and improvement (Patel: 2000, 134-5).

As a final point related to patents as an output indicator, it is important to say a word about the relationship between R&D and patents. This issue has been studied quite extensively by economists and management specialists for a long time. In fact, there seems to be a positive and significant relationship but the causality is not clear nor is the lag structure. "This raises the question about when patenting occurs in the R&D sequence" (Patel: 2000, 134).

2.2.2 Direct Measurement of Innovation: Innovation Counts

Innovations reveal a certain level of economic performance. This means that successful inventions have found a market. However, all innovations do not have the same weight. Some innovations will be used by a wide range of industries and generate immense payoffs while others like Cat Scan will be weakly diffused given the limited scope of the market for such a scientific instrument. This is often the case with science-based innovations. Therefore, measuring the economic performance of innovations on the basis of counts would be difficult and quite misleading.

There are essentially three methods for directly measuring innovations: the first is through the identification of significant innovations and their sources. These sources can be diverse and well beyond R&D activities. So that innovations not captured on the basis of R&D and patenting will quite likely be captured with the identification of significant innovations and their sources. The second approach is to collect and analyze new products announcements in trade journals and will be seen later in the paper. The third approach is through the assessment by a firm of its own level of innovations, reporting total costs of innovation, not just R&D but also design, testing, production engineering. This is mainly done through firm-level surveys. (Patel: 2000, 136-7)

2.2.3 Number of Publications and Citations in International Academic Journals: Bibliometrics

Measuring scientific output is not a recent activity. In the 1960s, Derek de Solla Price used a count of scientific papers to measure the output of basic science. Since this time, substantial improvements have been made to facilitate large-scale statistical application. This measure must take into account the quality control procedure. This occurs under the scrutiny of a system of referees. However, the quality of scientific journals varies and makes the assessment more difficult. A means to overcome this problem is to use citation to discriminate quality in the same manner as with patent citations as explained above. Over a period of time, it becomes possible to count the number of times a paper is cited by other authors. Although citation indices remain an imperfect measure of quality, it allows determining the role of individuals and institutions in the evolution of a specific discipline.

Companies also use bibliometrics to evaluate scientific and technical employees and their performance in order to generate prestige for the company. This is an important tool for the pharmaceutical industry. In addition, according to Geisler (2002) who cites Cockburn and Henderson’s study, there is a positive correlation between the number of company ‘stars’ and the use of such criteria to promote its R&D personnel. It seems that there is also a correlation between a tight interaction by firms with the scientific community, and success in drug discovery.

(Geisler: 2002, 7). However, bibliometrics cannot detect a firm's weakness in downstream activities of the innovation process. A firm can perform in generating publications and citations but be weak on the commercial side. As a whole, bibliometrics allows identification of the trends in science and technology. In some ways, it is a measure of the transfer of scientific knowledge.

2.2.4 Identification of Innovations on the Basis of Surveys, Sector Experts and Specialized Journals

While most studies on innovation have been conducted within a single discipline, i.e. economics, strategic management and finance specialists have been quite interested in developing indicators at the firm level (Tidd, Driver: 2000). The most common and reliable indicators used at the national level are nevertheless not very useful at the level of the firm. Because financial indicators concentrate on the short-term perspective, measures of profitability often undervalue innovation. Innovation can take time to produce economic value. Management of technology specialists therefore prefer to use financial ratios that reflect a long-term performance. For example, they use the stock market value as an output indicator arguing that "developments which cause the market to re-evaluate the future output of the firm should be recorded immediately" (Tidd,: 2000, 110) contrary to profits or return on investment which reflect the effect of innovation very slowly.

Some output indicators have been developed at the firm level. As is the case at the national level, the most common is the number of patents and the number of patent citations to determine the technological value of a patent. Other indicators are used in addition to these standard indicators to palliate their limitations such as the huge differences between sectors and companies in their disposition to patent and the limited information on innovative result as it reflects invention and not innovation especially in scientific knowledge based sectors. One procedure is the identification, by sector experts, of significant innovations successfully marketed along with the firm responsible for this innovation (Flor, Oltra: 2004, 327). The second method is to identify innovations by surveys of company managers. This is the approach chosen by the OECD in the Oslo Manual which led to developing innovation surveys in many countries enabling international comparisons. Finally, a *literature-based innovation output* (LBIO) method based on the publication of information on innovations in specialized journals. While the identification by sector experts and company managers is left to the perception by these specialists of what an innovation consists of, the LBIO seems to arrive at some consensus on its potential at the firm level[6]. Before expanding on the LBIO method, let us speak about innovation surveys.

They have been developed following the publication of the Oslo Manual. The main reasons for the development of these surveys are threefold: first of all, innovation goes beyond R&D; second, while input indicators of innovation exist, there is a lack of output indicators; and, finally, a need to better understand the conditions of innovative activities at the firm level (Guellec, Pattinson, 2001, 79). Schaan and Nemes underline the same motives behind the development of survey innovation. Mainly directed towards a need to inform governments, the information compiled in these surveys allows analyzing and determining the characteristics of innovative firms versus those of non-innovative ones (Schaan, Nemes: 2003, 17).

Let us come back to the LBIO. Product announcements are used by researchers to proxy product innovation in particular. As mentioned above, the method is called the *literature-based innovation output* (LBIO). These announcements are made in trade and specialized industry journals and according to management specialists, they provide a good measure of innovation outputs at the firm level. "It is based on the assumption that firms are interested in publicizing their new products and services once they are about to be launched on to the market" (Flor, Oltra: 2004, 327). As well, the interest of these announcements relies also on the fact that a description of the innovation is provided which allows more analysis in terms of its complexity and its nature, that is, it is founded on a specific knowledge basis. These indicators have many advantages over company surveys such as the fact that these data are collected without directly contacting companies[7]. The collection is rather inexpensive as it suffices to scan databases and trade journals. Finally, comparisons over time are facilitated given the data set can be extended into the past. However, they recognize some drawbacks as only product innovations can be captured since firms fail to advertise innovation processes. (Tidd,: 2000, 117, Flor, Oltra: 2004, 328). For innovations in products rarely patented, such as software or those in the service sector, this method fills an important gap left by patents.

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6 Coombs, Narandren and Richards (1996) provided an excellent description and review of this method explaining in details the main strengths and weaknesses and indicating some avenues and steps to follow in order to develop a database of innovation announcements.

7 Tidd and Driver (2003, 117) give the example of the *Predicasts F&S Index plus Text* database in which they get information on product announcement data. This commercial database contains abstracts from more than 1000 trade and industry journals worldwide. These data allow an analysis on the basis of company, product, country and event. The latter is essentially market information, people, resources, management procedures, etc. One problem with the abstract is that it is insufficient to inform and determine the type and complexity of the innovation.

In a comparative study using different indicators to identify technologically innovating firms in the Spanish ceramic tile industry, Flor and Oltra (2004) conclude concerning the suitability of the LBIO method which, in comparison to other indicators, (amongst those innovation surveys) succeeded in detecting the highest number of innovating firms. However, according to the authors, although this method shows great potential, certain characteristics of the industrial sector must be known in order to interpret the results properly. In conclusion and as emphasized by Flor and Oltra, it would be important to extend the application of these methods to other industrial sectors to identify the most suitable method.

2.2.5 Nation's Share of High-Technology Exports: High Tech Trade

In general, the high-tech trade has grown more rapidly than trade in other products (European Commission: 2003, 327). High-tech trade is defined as exports and imports of technical products whose manufacturing is highly R&D intensive. This indicator reveals a great deal about the industrial structure and technological capabilities of a country.

2.2.5.1 Technology Balance of Payments

High-tech trade involves exports and imports of products and services (e.g. sales of patents, licenses for patents, know-how, models and designs, trademarks, technical services) with a high intensity of R&D and which are at the leading edge of technological innovation. However, not all products traded by high-tech industrial sectors can be considered as high-tech products. It is important to distinguish exports and imports related exclusively to high-tech products and not to all products of a high-tech industrial sector. This indicator captures international trade in technical knowledge and services. It is very useful as it sheds light on a "…country's ability to sell its technological know-how, or conversely its dependence on importing foreign technology" (European Commission: 327). In fact, this is a meaningful indicator of technology diffusion.

Trends in high-tech trade reveal much about technological capability, the capacity to develop new knowledge. As the European Commission's report mentions, it "…reflects a country's ability to carry out research and development, and to exploit the results in the global markets" (EC: 2003, 354). Exports of these high-tech goods generate high value-added and well-paid employment and lead to an increase of overall productivity by the producing as well as the user sectors and have a linkage effect on learning and competitiveness. It also gives information about the technological specialization of countries. We could rightly expect that smaller countries will be technologically more specialized (Pavitt: 1988, 144).

Complementary information can be gained by looking at partners with whom trade is undertaken. These partners can change over time as well as products and services exchanged. Interpretation of these data must nevertheless be done with care. A European Report asked, "Is a high-tech trade deficit necessarily a bad thing?" In fact, the answer is not clear-cut since a strong import of high-tech goods could be beneficial to industries using such goods as they incorporate new knowledge. Moreover, as the report emphasizes, high-tech imports are likely to be complementary to exports of a country.

2.2.5.2 Software Trade

Trade of software goods and services is very difficult to measure. According to the OECD, the value of software traded is underestimated given it is based on the value of physical supports rather than of content (OECD: 2002, 110). Another problem for the measurement of trade is that software-related services are not distinguished from other services. We can also use the value of software royalties received and paid by a country to approximate the magnitude of software trade. This section can be concluded by warning that certain limitations exist as these data are not available for all countries and would require more harmonization.

2.2.6 Nobel Prizes as an Output Indicator of the State of S&T Worldwide

What kind of information does a Nobel Prize award convey? First of all, this is the highest scientific recognition an individual, in a specific country, in a specific field, at a specific moment can receive. Therefore, over a long period of time, significant information can be brought to light from the study of these awards. For example, during the last century we witnessed a shifting pattern of Nobel Prize laureates from Europe to the United States. This change is explained by the flight of scientists from Europe to the United States before World War II. The study of recent trends should also not lack interest.

> Firstly, it appears likely that it would be possible to identify which scientific fields are the most dynamic at present, information which might be useful in deciding on the allocation of R&D resources. Secondly, it may also be possible to identify which nations are the most advanced and successful in R&D, thus enabling an analysis of the reasons for their success to be carried out with the hope of replicating them (European Commission: 2003, 319).

It is tempting to rank countries in order on the basis of the Nobel Prizes. However, the geographical distribution of the laureates more reflects the location of the great research centres than the nationality of Nobel laureates. Given the fact that these eminent researchers are quite mobile, it is rather difficult to associate national conditions to the production of a Nobel Prize. Nationality is therefore of little use as a science and technology indicator (European Commission: 2003, 323).

Despite a certain potential to use Nobel Prizes as a science and technology output indicator, there are many difficulties to be conscious of in order to fully exploit it and use it as a guide to short term policy. As emphasized in the European Commission's report, it is worth remembering that often a lag of ten to twenty years had passed between the ground-breaking research and the reception of the award. The Nobel Prize is given for one original contribution only, which eliminates many scientists who have developed major contributions over a lifetime. A geographical analysis is not very realistic as the laureates have been quite mobile for the most part, and so nationality does not mean much. Finally, the correlation between the number of Nobel Prizes and the amount of money spent on R&D by a country is not clear.

Recently, two papers by Jones (2005a et b) have been written using Nobel Prizes to measure the productivity level of scientists by age considering the growing level of difficulty (or complexity) of innovation. Although this kind of information is limited in terms of science and technology potential at an aggregate level, it might constitute a strong potential for this indicator to be used to measure the contribution of a few individuals working at the frontier of technological change.

2.3 Composite Indicators

Composite indicators, "which are synthetic indices of individual indicators" (OECD: 2003, 5), the sum of its parts, have witnessed a great development recently. Supposedly, globalization has something to do with the development of such indicators. Mostly used at the aggregate level, they allow a ranking of countries and a better understanding of the complexity of convergence /divergence.

Patel and Pavitt have been pioneers in the field of innovative activities measurement for many decades and warned economists about the difficulty of developing and using a unique indicator perfectly reflecting science and technology patterns and performance. They advised using a combination of indicators in order to cover the whole innovation process more faithfully. According to them, there are no clear distinctions between invention, innovation and diffusion; it is rather an interactive process. They also mentioned that there is "…no unique and superior measure of innovative activities and technological levels. Each has its strengths and weaknesses, and any analysis or comparison should use a range of indicators adapted to its purpose " (Patel, Pavitt: 1987). We believe that their warning has led the way to considerable efforts invested recently in developing synthetic or composite indicators reflecting the innovation reality more precisely. In other words, the development of composite indicators is probably the result of this warning. In fact, knowledge-based economies have a multi-dimensional nature and only composite indicators can cover the numerous aspects of innovation. Recently, the European Commission committed a substantial report introducing composite input (investment) and output (performance) indicators. There is a significant trend toward the development of such indicators not only in relation to innovation but also for all realities presenting integrated components. For example, monitoring human capital faces the same complexity and, increasingly, international organizations try to proxy this capital using diverse aspects.

A variety of measures have been developed to appraise countries' technological capabilities. Of course, it is not the first time that synthetic indicators have been developed and used. The gross domestic product (GDP) is certainly the most known and used among aggregate indicators to measure and compare economic development.

> Although GDP has the great advantage in converting each aspect of economic life into a monetary yardstick (an advantage that only very few technological indicators have), it is equally evident that it highlights some aspects of economic and social life (such as income) and obscures others (such as well-being). (Archibugi, Coco: 2005, 176)

It suffices to mention some of the most well-known composite indicators such as that of the World Economic Forum (WEF)[8], the UN Development Program (UNDP), the UN Industrial Development Organization (UNIDO), the RAND Corporation, the Innovation Index by Porter and Stern and, finally, the ArCo (Archibugi and Coco) Index. These indexes are composed of a battery of variables and some exhibit the same information (Arcelus, Sharma and Srinivasan: 2003).

Indices are interesting as they combine a variety of variables and thus prevent biasing inputs, intermediate outputs, or output technology results too sharply. Technological capabilities of developing and developed countries are hardly comparable. The division is sometimes so profound that comparing these countries' technological capability raises challenges. So many variables are integrated into these indicators that the subtlety of differences tends to be confounded.

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[8] The Forum assesses the competitiveness through two complementary indicators: the first, the *Growth Competitiveness Index* (GCI), was developed by Sachs and McArthur and, the second, the *Business Competitiveness Index* (BCI), by Porter. The GCI was developed in order to gauge the capacity of countries to achieve sustained economic growth over the medium and long term while its complement, the BCI, looks at a range of company-specific factors conducive to productivity at the micro level.

The ‘Lisbon strategy’ set targets and encouraged the development of such indicators to monitor the reaching of these targets. The European Commission developed two composite indicators – one of investment and one for performance – in the knowledge-based economy. The former measures the level of investment in the creation and diffusion of new knowledge while the second measures the outcome of this investment. Amongst sub-indicators included in the first composite indicator, there is total R&D expenditure per capita, number of researchers per capita, new S&T PhDs per capita, total education spending per capita, life-long learning, gross fixed capital formation (excluding construction) and *e*-Government. The composite indicator of performance (overall productivity, technological performance, scientific performance, information infrastructure and effectiveness education) includes sub-indicators of labour productivity, patenting activity, scientific publications, *e*-commerce and schooling success rate.

Although a huge variety of composite indicators have been developed, only three will be introduced as they are different and address innovation in their own way. The first one is the Innovation Index by Porter and Stern, the second is the ArCo Index developed by Archibugi and Coco and the last one is the Overall Competitiveness Index of Fagerberg.

2.3.1 The National Innovative Capacity Index

This Index is a quantitative benchmark of national innovative capacity. As the authors say, the focus is not on scientific progress or competitiveness but on the concept of *national innovative capacity* that they define as ‘the ability of a country to produce a stream of commercially relevant innovations’. More specifically, the goal of their index is to provide one metric to comparatively evaluate national innovative capacity in an international context. They affirm that the index does not measure the ability of countries to be successful at a given point in time or to commercialize current technologies but rather captures the potential to sustain productivity growth and competitiveness in the long term (Porter, Stern: 1999, 39). In some ways, it is a reflection of national institutions, that is, the resource commitments, infrastructure and specific conditions evolving around innovation and policy choices of a specific country in relation to other advanced countries and newly industrializing countries.

> Innovative capacity depends in part on the overall technological sophistication of an economy and its labour force, but also on an array of investments and policy choices by both government and the private sector. Innovative capacity is related to but distinct from scientific and technical advances per se, which do not necessarily involve the economic applications of new technology. Innovative capacity is also distinct from current national industrial competitive advantage or productivity, which

> result from many factors (such as the skills of the local workforce and the quality of physical infrastructure) that go beyond those important to the development and commercialization of new technologies. (Furman et al: 2002, 905)

This innovation index includes measures reflecting 1) the common innovation infrastructure; 2) the innovation environment in clusters and; 3) the quality linkages between those two areas. To capture the common innovation infrastructure, the authors use direct measures such as aggregate personnel employed in R&D, aggregate expenditures on R&D, openness to international trade and investment, strength of protection for intellectual property, share of gross domestic product spent on secondary and tertiary education and gross domestic product per capita. The quality of the second component 'Cluster-Specific Environment for innovation' is proxied by using private R&D funded by private industry and, finally, the quality of linkages between these two components is measured on the basis of the percentage of R&D performed by universities.

This index is particularly interesting as the authors do not simply accept each of the measures chosen as valid. To make their index more adapted and valid, they assess each measure on innovativeness through statistical analysis by regressing them on the level of international patenting – a proxy for national innovative output. Then, they calculate the index on a *per capita* basis, that is, a measure of innovation intensity that facilitates the comparison between countries allowing small countries to rank high as often as large countries.

While they select international patenting as the best available measure of a national innovative output[9], they nevertheless recognize the limitations of this indicator, although these limitations are less pronounced than other measures. At the least, it measures innovativeness at the world frontier and captures the capacity of a country to develop 'new to the world' technologies. Their conclusions are worth mentioning as measures used in their index explain 99% of the variation across countries in international patenting. What is more striking is that no single factor was dominant in explaining innovative capacity. While R&D personnel, R&D spending and business share of R&D spending were the three largest explanatory variables, other factors also contributed to affect innovative output. This supports the early work of Pavitt (1987) who criticized the use of a unique indicator to reflect the innovation capacity of a country.

Finally, it would be interesting to calculate this index at the sectoral level instead of at such an aggregate level. However, it is worth recalling that this task would be extremely tedious as patents could not be attributed to a specific industry *per se* as explained above. Patents are a measure of technological change and these technologies can irrigate many industrial sectors. They are not located in a

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[9] They consider that an international patent reflects commercial significance.

specific industrial sector.

An index of specialization would be interesting for small countries like Canada although small Scandinavian countries, on the basis of this index, generally outperform larger countries. In fact, what this index says is that Canada 'is holding the line' in terms of spending and environment (which are constant) and, as a result, slips back in terms of the ranking.

2.3.2 ArCo Index

Another example worth introducing is the ArCo Index that aims at measuring the technological capabilities of a country, a fundamental component of economic growth. This index has been developed in the context where measures of technology combining different data are in demand in order to better understand how and why countries differ in terms of growth (Archibugi, Coco: 2005, 187). As Archibugi and Coco argue, '…to measure technological capabilities is more complicated than to measure other economic and social indicators. The very nature of technology makes it difficult to aggregate its heterogeneous aspects and components into a single meaningful indicator'. (Archibugi, Coco: 2005, 176). According to them, a battery of indicators will provide a more comprehensive picture of differences and similarities than a unique indicator would.

Sub-indexes composing the indicator of technological capabilities of ArCo index are technology creation (patents granted per capita, S&T publications per capita), technology infrastructure (internet users per capita, telephone mainlines and mobiles per capita, electricity consumption per capita), human skills (tertiary science and engineering enrolment ratio, mean years of schooling over 14, literacy rate). The methodology of aggregating the sub-indexes is the result of the simple mean of these three sub-indexes and each sub-index is the simple mean of the indicators in each category (Archibugi, Coco: 2005, 185). See the Table 1 for more details on the structure of the Arco Index.

2.3.3 Composite Indicator of Competitiveness

Fagerberg and his colleagues (2004) wrote some interesting papers in order to better understand and find measures of the overall competitiveness issue. Strongly influenced by the Schumpeterian logic, they outlined a theoretical framework and on this basis developed composite indicators which have an interesting appeal for understanding the overall competitiveness of a country. As described in the first section of this paper, the Schumpeterian logic and especially its evolutionary followers, depart from standard neo-classical approach and reject the perfect competition assumption, the public nature of technology. They consider that the latter is cumulative, risky, and path-dependent.

Table 1
Indicator of Technological Capabilities (ArCo)

Sub-indexes (weights)	Individual indicators (weights)	Sources	Formula to compare individual indicators	Years and countries
Technology creation (1/3)	Patents granted at USPTO per capita (1/2) S&T publications per capita (1/2)	USPTO (2002) NSF (2000, 2002)	(Observed value – minimum value)/ (maximum value – minimum value) index range [0,1]	1987-1990; 1997-2000; 162 countries
Technology Infrastructure (1/3)	Internet users per capita (1/3) Telephone mainlines and mobile per capita (1/3)	ITU (2001) World Bank (2001)		
Human skills (1/3)	Tertiary science & engineering enrolment ratio (1/3) Mean years of schooling over 14 (1/3) Literacy rate (1/3)	Unesco (2002) Barro and Lee (2001) UNDP (2001)		

Source: Archibugi, Coco: 2005, 191

For them, the nature of capitalist competition is not so much about price competition but technology competition[10]. Although Fagerberg and his colleagues consider cost competitiveness as part of their overall competitiveness

[10] Obviously, a country could achieve higher cost competitiveness by depreciating its currency and slower growth in wages but the end result would not be positive for living standards (Rao, Tang, Wang: 2002, 15).

indicator, technology and capacity competitiveness are the core ones. An aspect of their competitiveness indicator is labeled *technology competitiveness.* This component is closely related to the innovativeness of a country or, put in other words, refers to the ability of a country to compete successfully for new goods and services in markets. R&D expenditures, patent statistics and scientific publications are included in this indicator. See Table 2 for more precise details on the composition of these indicators.

Then, they go further than technology competition and borrow Gerschenkron's suggestion according to which a country close to the technology frontier will tend to stimulate growth and competitiveness in latecomer countries. Borrowing from empirical models of the catching-up literature, they develop a *capacity competitiveness* indicator. This precise indicator also refers to the appropriability capacity of a country, that is, 'the degree to which firms [in this country] can obtain economic returns to various kinds of innovation (Dosi: 1988, 229) The two indicators – technology and capacity competitiveness – are multidimensional and hard to measure.

Four dimensions composed the *capacity competitiveness*: human capital, ICT infrastructure, diffusion and institutions. These components allow determining the superior capacity of a country to exploit a technology even though this country did not develop the technology. In other words, it relates to the absorptive capacity which enables countries to assimilate technologies and obtain economic returns.

Although standard measures, estimates of price or cost competitiveness, i.e. unit wage costs in manufacturing in a common currency, present difficulties especially when numerous countries are to be compared[11].

Demand competitiveness is the last component of their overall competitiveness indicator. With this indicator they intend to capture the ability of a country to exploit the changing composition of demand. This is captured on the basis of the growth of world demand (by commodity) by the commodity composition of each country's exports (Fagerberg et al: 2004, 20).

When possible, these authors defined indicators as activities measured in constant prices or quantity, deflated by population and normalized in the following way: Actual value — mean value/ standard deviation.

[11] According to the authors, many components could not be taken into account such as benefits related to wages given the lack of data for many countries.

Table 2
Composite Indicators of Technology and Capacity Competitiveness

Dimension	Sub-component	Indicator	Scaling	Source
Composite Indicator of Technology Competitiveness				
S&T inputs	R&D Expenditures	GERD	per capita	World Development Indicators; OECD Main Science and Technology Indicators; Science & Technology Ibero-American Indicators Network, national sources
S&T outputs	Scientific publications	Scientific and technical journal articles	per capita	World Development Indicators
	Patenting activity	USPTO patent grants (inventor's residence country)	per capita	OECD Patent database
Composite Indicator of Capacity Competitiveness				
Human Capital	Tertiary education	Tertiary school enrolment	% gross	World Development Indicators; Unesco, Global Education Database by USAID
	Secondary education	Secondary school enrolment	% gross	World Development Indicators; Unesco, Global Education Database by USAID
ICT Infrastructure	Computers	Personal computers	per capita	World Development Indicators; International Telecommunication Union
	Telecommunication	Fixed line and mobile phone subscribers	per capita	World Development Indicators; International Telecommunication Union
Diffusion	Embodied technology	Gross fixed capital formation	per capita	World Development Indicators
	Disembodied technology	Royalty and license fees: payments	per capita	World Development Indicators
Social aspect	Corruption	Corruption Perception Index	Index	Transparency International

Source: Fagerberg, Knell, Srholec (2004)

According to the authors, "there is a lot of diversity in how countries perform" (Fagerberg, Knell, Srholec: 2004, 11). In offering four indicators of competitiveness – technology competitiveness, capacity competitiveness, demand competitiveness and cost competitiveness, they single out some general factors explaining the wide differences of economic performance across countries.

On the basis of these empirical indicators that deal with several aspects of competitiveness, they apply them in an analysis of the differing performance of countries according to which the rate of economic growth of a specific country is the weighted sum of the potential of diffusion (using the difference between the level of GDP per capita in the country and average GDP in countries included in the sample deflated by the GDP per capita of the leading country), the growth in technological competitiveness, growth in capacity competitiveness, the growth in cost competitiveness and, finally, the demand competitiveness relative to that of other countries (.Fagerberg, Knell, Srholec: 2004, 21).

Two important advantages of this composite indicator are worth reporting. First, it is based on theoretical approaches and second, this indicator includes measures of technology generation and technology adoption. These two strengths are often cited as the limitations of composite indicators.

2.3.4 Limitations of Composite Indicators

Although composite indicators could be an interesting avenue to measure multiple dimensions of science and technology, there are problems related to these indicators. According to Grupp and Mogee, "the problems with the use of benchmarks or scoreboards on a national level lie in the lack of clear theoretical models to guide selection and weighting of indicators and handling of cross-country differences in the availability of data" (Grupp, Mogee: 2004, 1378). A discussion of the validity of the numbers, of a transparent structure and recognized concepts must accompany the development of composite indicators to avoid manipulation on the basis of selection, weighting and aggregation. As an alternative to composite indicators and to avoid manipulation, Grupp and Mogee suggest, "Maps of similarity between country structures in science and technology may have more explanatory power in particular when combined with non-quantitative methods" [12](Grupp, Mogee: 2004, 1383).

[12] So that it would be interesting to integrate the Hall and Soskice model in order to understand the role of institutions and organizations in different types of political economies. (Hall, Soskice: 2003, 8) Considerable studies have been done to document similarities and differences of institutions of the National System of Innovation (N.S.I.) but this should be extended to other institutions indirectly related to innovation institutions (e.g. industrial relations institutions) such as Hall and Soskice documented in their study.

<u>PART 3:</u> MEASURING INNOVATION AT DIFFERENT UNITS OF ANALYSIS

In this section, an attempt will be made to locate the variety of innovation indicators described in the second section of this report at different levels of analysis. Drawing on the literature outlined in the first section will give a better appreciation of the use and relevance of various indicators: some performing better at the firm or industrial sector while others more adequately represent the aggregate or national level.

3.1 Cross-Country Differences in Innovation

Measuring competitiveness has become an obsession according to Krugman (2001). However, competitiveness has multiple components and innovation is among them. Traditionally, innovative activities have been ignored in studies trying to answer why growth differs between countries. More recently, many attempts to understand the role of innovation in economic growth have been made but these attempts have mainly been found outside mainstream economics. Besides, it is not too surprising to rarely find published work of Schumpeterian flavour in mainstream economics journals.

What is particular about Canada’s R&D performance is that it is relatively weak despite a relatively good overall growth performance as measured by total GDP (Harris: 2005, 3). In fact, the weak link is labour productivity growth in the business sector where Canada achieved in the 2000-2003 period, a growth of 1.34 percent as compared to 3.77 for the United States (Harris: 2005, 3). Innovation performance should lead to productivity growth as well as economic growth. Since Canada lags considerably behind in BERD, this could explain its slower rate in productivity growth compared to the United States. However, the relationship between R&D and growth is relatively difficult to establish. While there is substantial consensus on the role of R&D on innovation, it cannot explain Canada’s highly prosperous economy though it might reflect its poor labour productivity growth. Is it because current indicators of innovation cannot capture the specificity of Canada’s innovation capacity? It might be because Canada is not so much a generator as an assimilator of technology, and that R&D as a whole cannot capture it. Perhaps disaggregating R&D into its components – fundamental research, applied research and development – would lead to more precise findings. In the next section, it will be shown that capital intensity, i.e. Machinery & Equipment, which is more an indicator of technology adoption than of technology generation, is quite useful to explain growth in a country like Canada. In any event, this could become an interesting avenue of research along with a more comprehensive study of different sources of innovation.

Another important research avenue at this level of analysis concerns the development of composite indicators as they are especially relevant at the national level. In Part 2, we introduced three main composite indicators: that of Archibugi and Coco, that of Porter, and that of Fagerberg. What can we conclude about the use of such indicators to explain economic and labour productivity growth? Each one measures a different aspect of innovation and their weighting as well as their methodology differ considerably.

Our preference will be given to that of Fagerberg et al's for two good reasons. The first reason to plead for this indicator is that it includes the two important faces of innovation, that is, technology generation through the *technology competitiveness* index and technology assimilation through the *capacity competitiveness* one. In addition to these two components, it also includes *demand competitiveness* which allows capturing the ability of a country to exploit the changing composition of demand as explained in the last section of this paper. *Cost competitiveness* is not left aside either so that a more complete picture is provided. This composite indicator constitutes a good tool box.

A second good reason to retain this indicator is that it is founded on a very solid theoretical background which at the same time combines assumptions of the evolutionary economics approach and of Gerschenkron's catch-up tradition. These indicators are therefore supported by solid theoretical foundations and thus have not been developed randomly.

3.2 Measuring Innovation across Industries

The sources contributing to the enhancement of long-term growth are not well understood. As seen in Section 1 of this paper, it took some time before technological change was considered as a basic factor in economic growth and labour productivity by economists. Influenced by Schumpeter's theory, economists not only began to consider its core role but also looked at how to measure its impact, and started to search for the best proxy measures to take its role into account, not only at the aggregate level but also in firms and quite importantly, in a dynamic fashion considering flows of technology across industrial branches.

However, aggregate regression analyses are not very precise and have been severely criticized (OECD: 2005), so that looking at growth by industry can be an interesting alternative and could give a better understanding of the role of technological change in growth as different industries have different innovation activities, different sources of innovation, different dynamics and therefore different intensities of investment in their sources of innovation. Furthermore, as countries have a different industrial configuration, this could provide a more accurate picture of innovative activities of firms in a specific country.

While the industrial sector is probably the most adequate unit to study innovation when international comparisons are involved, given the differences of industrial composition between countries, technological change is not compatible with industries as a unit of analysis. Putting it in other words, technologies follow trajectories that go well beyond industrial boundaries. They tend to irrigate numerous industrial sectors (due to the spillover effect). Therefore, focusing on vertically integrated industrial sectors such as economists are used to doing is likely to impose a considerable bias on a study of technological change. If vertically integrated sectors are not compatible with studies of technological change, some economists inspired by evolutionary economics have suggested looking at sectoral patterns of innovation in order to capture industrial dynamics which can be located at a more aggregate level than the standard vertically integrated sector.

In order to explain the usefulness of classifying sectors into sectoral patterns of technological change, this section will first present some evidence of the variety of innovation patterns taking into consideration the distinctive character of the composition of Canadian industrial structure. We will use the empirical work of Ab Iorwerth to illustrate this. An emphasis on some high-tech sectors will also be made and compared to the United States. Such an examination reveals only the tip of the iceberg, that is, certain peculiar features of innovation in Canada. To get a more comprehensive picture, in a second part of the section, we suggest looking at some taxonomic exercises which could help reveal a more systematic picture of the Canadian industrial structure and of patterns of technological change at the same time.

3.2.1 Innovation and Industry Composition

As explained earlier in this paper, it is not easy to account for the low aggregate R&D intensity in Canada. Can we find an explanation in structural factors related to Canada's large natural resource base? (Harris: 2005). Does the Canadian industrial composition constitute a barrier to BERD performance in Canada? Ab Iorwerth downplays the role of industry composition very often cited by economists as the main reason for the relatively low Canadian aggregate R&D intensity. He suggests examining the combination of share of GDP of a particular industrial sector – as much in the manufacturing as the services sectors – with its R&D intensity and comparing Canada and the United States' patterns. The comparative statistics are shown in the following three tables.

Table 3
Statistics on Manufacturing in Canada and the United States

	Canada			U.S.		
	Share of R&D	Research Intensity	Share of GDP	Share of R&D	Research Intensity	Share of GDP
Office + Comp. equip.	4.9	53.6	0.1	5.2	25.8	0.4
Radio, tel., com equip	28.9	27.9	1.1	20.6	20.5	2.0
Pharmaceuticals	6.5	27.5	0.2	6.8	21.0	0.6
Other trans equip	12	14.5	0.9	8.8	24.3	0.7
Elec. Machinery	1.1	3.6	0.3	2.3	10.9	0.4
M&E nec	2.5	2.1	1.3	3.5	5.5	1.2
Ref petrol, plast+ chim	3.4	1.6	2.2	5.8	5.3	2.1
Basic metals	1.4	1.3	1.2	0.3	0.9	0.5
Textiles	0.7	1.1	.7	0.2	0.6	0.6
Fab. met products	1.2	1.0	1.2	0.9	1.6	1.2
Furniture	0.6	.8	0.8	0.5	1.6	0.6
Motor vehicles	2.0	.8	2.9	10.1	15.3	1.3
Food +beverages	1.2	.6	2.3	.9	1.0	1.7
Wood and paper	1.5	.4	4.1	1.6	1.4	2.2
Other min products	0.1	.3	0.5	0.3	1.5	0.4
Total manufacturing	**68.0**	**3.7**	**20.0**	**68.0**	**8.3**	**16**

Source: Ab Iorwerth (2005)

Table 4
Statistics on Service in Canada and the United States

	Canada			U.S.		
	Share of R&D	R&D Intensity	Share of GDP	Share of R&D	R&D Intensity	Share of GDP
Com. social and pers. Service	0	0	19.8	0	0	21.2
Hotels and restaurants	0	0	2.4	0	0	0.9
Transport and Storage	0.2	0.1	4.3	0.3	0.2	3.2
Financial Intermediation	2.0	0.3	7.0	0.9	0.2	8.0
Post. and telecom.	0.9	0.4	2.8	0.9	0.5	3.4
Wholesale and retail	7.4	0.7	11.3	11.1	1.3	17.1
Real estate and business activities	19.3	1.1	18.4	12.2	1.1	21.0
Other	--	--	--	6.4	--	--
Total Services	**30.0**	**0.5**	**66.0**	**32.0**	**0.8**	**74.8**

Source: Ab Iorwerth (2005)

Table 5
R&D Intensity* of Selected High-Tech Industries

	BERD as % GDP	Pharma-ceuticals	Rank	Office Machinery Computer	Rank	Radio Telephone Comm. equipment	Rank	Motor vehicles	Rank	Other Transport Equipment	rank
1. Sweden	2.84	48.0	3	13.9	9	64.8	1	24.6	1	19.9	5
2. Finland	2.19	57.1	1	22.0	4	25.6	7	3.6	12	3.7	12
3. Japan	2.08	21.5	9	37.7	2	17.8	13	13.1	4	10.7	9
4. U.S.	1.99	21.0	10	25.8	3	20.9	10	15.3	3	24.3	3
5. Korea	1.76	3.9	14	7	13	17.9	12	8.9	10	1.1	15
6. Germany	1.7	--	--	16.7	6	36.2	3	19.2	2	28.1	2
7. Belgium	1.4	25.9	7	14.9	8	35.2	4	4.0	11	7.1	11
8. France	1.38	27.6	5	13.3	10	34.1	5	13.1	4	28.8	1
9. Denmark	1.32	34.9	4	18.3	5	15.0	14	0.0	15	10.1	10
10. U.K.	1.25	54.2	2	3.1	14	13.7	15	10.3	8	22.1	4
11. Canada	1.02	27.5	6	53.6	1	27.9	6	0.8	14	14.5	6
12. Norway	0.95	23.1	8	16.5	7	54.5	2	10.4	7	1.8	14
13.Ireland	0.88	7.1	13	2.3	15	24.1	8	12	6	2.7	13
14. Italy	0.51	10.7	11	9.3	11	22.3	9	9.7	9	13.7	7
15. Spain	0.46	10.1	12	7.5	12	19.1	11	2.6	13	13.0	8

Source: Ab Iorwerth (2005)
*as % of value added

The results are interesting. In fact, they reveal that despite the relatively low aggregate business research and development intensity in Canada, some high-tech industries have high research intensities according to international standards which do not translate, given the relative small size of these industries when compared with those of the United States. This is the case for Office, Machinery and Computer Industries and to a lesser extent for Radio, Telephone and Communication Equipment (Table 3). While Canada ranks first for the former, it ranks sixth for the latter, though well above the U.S. and Japan. On the reverse side, while the motor vehicles industry in Canada is larger as a share of GDP than that of the United States, its R&D intensity is comparatively very low. A glance at Table 5 shows that Canada ranks fourteenth out of fifteen countries in comparison to other countries in terms of BERD intensity in this sector. To conclude, one could quote the author of the study, “These results suggest that Canada’s lower aggregate R&D intensity does not reflect lower R&D intensity across all Canadian industries, but is instead caused by very low research intensities in a few industries” (Ab Iorwerth: 2005, 8). So that looking at the aggregate R&D intensity is likely to mask the good performance of some research-intensive industries. On the basis of the Canadian picture, the author points out that using the traditional explication to interpret the low aggregate research intensity in Canada according to which it is related to its large resources sector, does not hold.

One conclusion of this exercise at the industrial level would be that we need to examine very closely the industry composition effect on a national basis. To do so, it would be necessary to understand better the dynamics of these industries, that is, the technological linkages amongst the different categories of firms. In the analysis presented above, only R&D was used as a source of innovation despite the fact that the author recognized the possibility of firms obtaining technology from a variety of innovation sources.

3.2.2 Sectoral Patterns of Innovation

On the basis of the OECD report on the sources of economic growth, there seems to be evidence that labour productivity growth is related to performance improvement within industries rather than between industries (OECD: 2003, 97). Here is a good reason to look at industrial patterns of innovation.

To illustrate the patterns of industrial dynamic and the 'systemic-ness' within a country, Pavitt (1984) developed his taxonomy on innovative activities, stressing their sectoral differences and inter-industrial connections in terms of technology. The classification scheme was based on a very extensive database on innovation in the UK. One important aspect of this taxonomy is that there are many sources of innovation beyond organized R&D activity. As a matter of fact, this is in line with Ab Iorwerth's conclusions which can be read as follows, "…knowledge can be developed through R&D or absorbed by investing in machinery and equipment that embodies that knowledge. In other industries, this option may not be so readily available (such as pharmaceuticals potentially)" (Ab Iorwerth: 2005, 16). Pavitt found systemic interdependencies across sectors and what seems to matter most is not so much the relation specific firms have with basic science institutions such as public laboratories or universities, but rather their interaction with users, competitors, suppliers[13]. He also found that not only so-called high-tech industries are innovative but that low-tech ones can, in their own way, be an important vehicle for innovation. While the usual way of classifying industrial sectors on a technology basis is to distinguish between 'high-tech', 'medium-tech' and 'low-tech' defined on the basis of technology intensity, Pavitt built his taxonomy by taking into account the sources, rates and directions of technological change which differ across industries both in manufacturing and services. He challenges this huge variety by saying that behind it, there must be regularities, though not necessarily expressed on the basis of firm size or industrial concentration. Table 6 summarizes some important features of the taxonomy. Amongst them, we can see the variety of sources of innovation related to different categories of firms. This is the kind of

[13] This was also an important finding in Scherer's (1982) paper.

information needed to use and develop indicators relevant to the specific nature of innovation in specific industrial sectors. More precisely, it shows that R&D is only one source of innovation; many other sources should be used and integrated in the development of indicators.

Table 6
Five Major Technological Trajectories

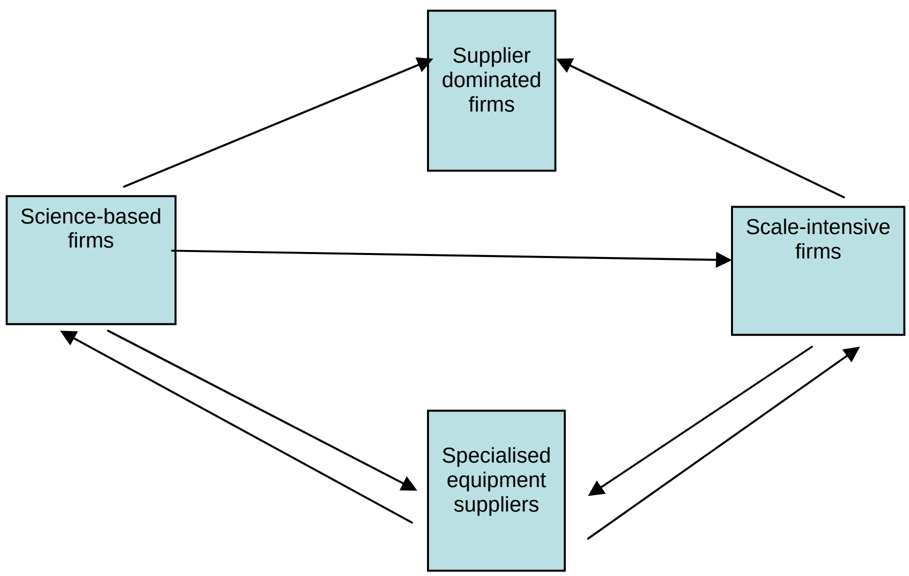
	Supplier-dominated	Scale-intensive	Information-intensive	Science-based	Specialized suppliers
Typical core sectors	• Agriculture • Services • Traditional manufacture	• Bulk materials • Automobiles • Civil engineering	• Finance • Retailing • Publishing • Travel	• Electronics • Chemicals	• Machinery • Instruments • Software
Main sources of technology	• Suppliers • Production learning	• Production engineering • Production learning • Design offices • Specialized suppliers	• Software and systems departments • Specialized suppliers	• R&D • Basic research	• Design • Advanced users
Main tasks of technology strategy	Use technology from elsewhere to strengthen other competitive advantages	Incremental integration of changes in complex systems. Diffusion of best design and production practice	Design and operation of complex information processing systems Development of related products	Exploit basic science Development of related products Obtain complementary assets Redraw divisional boundaries	Monitor advanced user needs Integrate new technology incrementally

Source: Tidd, Bessant, Pavitt: 1997

Figure 1 (in Annex B) has been taken from the initial paper written by Pavitt (1984) on his taxonomy. The categories differ from Table 6 above as the figure was developed in 1984 and the table, thirteen years later. However, since this time many scholars have been involved in this type of exercise given the development of innovation surveys which have been extremely helpful in performing it. In Figure 1, we can see the richness and complexity of information grasped on the basis of this exercise.

In Figure 2, technological flows emerging from the taxonomy are represented. For example, one can see that the supplier-dominated category of firms (essentially composed of firms from the agriculture, housing, and traditional manufacturing sectors) get their technology from science-based and scale-intensive industries. The science-based industry irrigates the scale intensive and specialized equipment supplier categories and in turn, the latter will be a source of technology for the category of science-based firms. These linkages can take the form of purchase or sale of goods embodying technology but can also include flows of information and skills. In addition, some diversification trends of firms can be explained and somewhat predicted on the basis of these flows[14].

Figure 2
Main Technological Linkages amongst Different Categories of Firms: Pavitt's Taxonomy



Source: Pavitt :1984

In fact, there have been many attempts and variants of industry classifications based on patterns of innovation. This is because researchers did not succeed well in grasping the role of technological change at the aggregate and micro level, and is why it is so important for policy purposes, as pointed out by some academics. "It is easier to work with a few well-defined industries than with a multitude of heterogeneous firms" (Raymond, Mohnen, Palm, Schim van der Loeff: 2004, 2). The quality of a classification is related to its degree of

[14] Although it is well beyond the scope of this report to discuss the issue of firm diversification, it is well to note that this taxonomy has been used by business management and scholars to explain diversification patterns of firms exploiting technological synergies (technological propinquity diversification). On the basis of these patterns, the author can draw some patterns of technological diversification and the location of this diversification in the industry (upstream, downstream and concentric), the intensity as well as the direction of the strategy of technological diversification.

homogeneity and in the case of innovation, which interests us more particularly here, innovative behaviour of different firms must show a high level of homogeneity to be gathered together. While twenty years ago data could hardly lead to building such a taxonomy, nowadays, innovation surveys conducted in many countries and at the European Community level have allowed a more systematic means of developing such classifications. Reviewing three taxonomies taking into account the innovation behaviour of firms, Raymond *et al* (conclude that Pavitt's taxonomy "is the most useful for innovation policies". Their reasoning follows here:

> As the OECD taxonomy relies on a single innovation input indicator, R&D intensity, it is too narrow and will be incomplete for policy purposes…The PCA approach considered by Baldwin and Gellaty (2000)…is not fully satisfactory…is not of great help in recommending innovation policies, since it is based on firm level characteristics, while policies are very often industry-based…The Pavitt taxonomy is the most useful of the taxonomies considered here for innovation policies. It accounts for various criteria of the innovation process to classify industries, and its policy implications are based on a 'theory' derived from experts opinions about industries and empirical evidence. However, the Pavitt taxonomy is based on the population of innovating firms. There is no information regarding the classification of non-innovating firms. Therefore, it provides no guidance for policy measures to encourage non-innovating firms to become innovators. (Raymond et al: 2004, 6)

However, to respond to the criticisms on non-innovating firms, we must emphasize that innovation surveys can shed some light on this issue as innovating and non-innovating firms are included in these surveys.

Raymond *et al* (2004) who proposed an empirically-based industry taxonomy taking into account various input and output indicators of innovation, estimated a model of determinants of innovation and tested the homogeneity among industries. They aim at going further than descriptive statistics and propose testing the homogeneity of their industrial categories on the basis of an empirical model. This is a model of the determinants of innovation explaining the behaviour of enterprises. Classified into categories of variables –- enterprise characteristics, enterprise activities and industry characteristics — the determinants of innovation are as follows: size of an enterprise, relative size, demand pull, technology push, subsidy, cooperation under the first category; R&D intensity, continuous R&D, non-R&D performer for the second category and, finally, a two-digit classification.

One of the conclusions of their model in terms of determinants is that "R&D remains one of the foremost innovation input indicators. To promote innovation, R&D should be stimulated in the high-tech and low-tech categories" (Raymond *et al*: 2004, 32). This will constitute an interesting proposition to be tested as other classifications do not necessarily share this conclusion. Although it is well beyond the scope of this paper to compare all these variants, such an exercise should be undertaken as a multitude of classifications have been developed, especially in European countries. Annex A provides a synoptic though partial table of a list of these taxonomies.

3.3 Measuring Innovation at the Firm Level

Innovation does not happen exclusively in firms as it can take place in hospitals, universities, public laboratories, etc., but firms are quite often the locus where innovation occurs, although sometimes in close interaction with external partners. So that strategic choices of innovation style by a firm and its management can reveal much about innovation success or failure. We need to transcend disciplinary boundaries and borrow from management, strategy and business studies to have a better understanding of technological change within firms. The choice of indicators best used to measure innovativeness at the firm level is closely determined by the sectoral branch where the firm is located. Sometimes, it might cross more than one industrial branch.

3.3.1 Research and Development at the Firm Level

The most important player in private R&D is the enterprise. However, enterprises are quite varied since they belong to different industrial sectors and various networks of users/suppliers have various sizes. They can also finance R&D without being performers of R&D. Research and development is often used to identify innovating firms as this information is made available in some countries for some sectors. However, this is not always the case as this information tends not to be consistently public for an individual firm; secrecy around this expenditure creates limited access to researchers. Another problem with this indicator at the firm level is that it tends to underestimate the technological activities of smaller firms as they do not often carry formal R&D budget. (Flor, Oltra: 2004, 324-5). Once again, innovation surveys made this task easier.

3.3.2 Firm Size

The most common indicator used to predict the probability to invest in R&D is the size of a firm. As pointed out by Pavitt, we should avoid general and sterile debates about the relative contribution of large and small firms to innovation (Pavitt: 1984, 370). To avoid such generalizations, it is necessary to have a good understanding of the inter-industry differences. At least this is a conclusion that Pavitt and Ab Iorwerth share. In other words, a close analysis of inter-industrial technological linkages and inter-industrial differences amongst categories of firms in a national system of innovation would be essential. To illustrate this point, let us use two categories of firms – supplier dominated and specialized equipment suppliers – in the Pavitt taxonomy. Although innovating firms in both categories share approximately the same size, i.e. they are small firms, they follow different technological trajectories. They do not share the same sources of technology, their users do not have the same needs, and the means of appropriating the benefits are different. The former category is closely integrated with their suppliers, which are scale-intensive firms and their technological strategies are driven by cost-cutting expectations, while the latter is composed of small but highly sophisticated firms in terms of technology. Scientific instruments firms are part of this category. Their users (e.g. surgery specialists) are very knowledgeable and can impose their views on the development of a specific instrument such as a knee prothesis. Quite often they know very precisely what type of design an instrument should have and so they become quite closely involved in the technological process that is part of the production of this scientific instrument.

The second category of firms belonging to the supplier dominated category is quite often composed of firms located in traditional manufacturing. As a result, their clients or customers are not especially knowledgeable, which does not really matter since the level of technological sophistication is not very high. In fact, as explained above, since their technological strategies are cost-cutting, they contrast tremendously with that of firms located in the specialized suppliers category of firms. Even though they are both in average small firms, they differ completely in terms of technological trajectories.

It would be very useful to expand this taxonomy to the service sector in order to understand better the dynamics involved between manufacturing and service industries. For example, knowing about the magnitude of outsourcing from the manufacturing sector to the services sector could reveal important facts about the shift of innovative activities towards services. This could also explain the decreasing intensity of R&D in the manufacturing sector at the expense of that in the services ones. Outsourced from manufacturing, the same innovative activities previously accomplished in manufacturing firms might be found in firms of a much smaller size in the service sector.

3.3.3 Beyond Manufacturing: Service Sector as a Specific Case

Innovation is determined differently and takes place in different ways across industrial sectors. Can we transpose existing measurement concepts from manufacturing to the service sector? This leads us to ask another question, can the notion of innovation be used in a similar way in the manufacturing and service sector? Answering these questions is paramount since the passage to a knowledge-based economy implies a more significant contribution of service industries, especially the knowledge-intensive business service companies that play an increasing role as knowledge brokers and intermediaries (Hipp, Grupp:

2005, 518). According to these authors, the character of innovation activities differs substantially from the industrial sector and, consequently, new forms of indicators are needed.

Some differences can be described as follows: service companies do not pursue standard R&D activities, patent protection is not very important and the intangibility of innovative output makes it difficult to identify and measure the output.

> '…in the service sector, innovations are more knowledge-intensive (human capital intensive) than technology (R&D) intensive. Innovations in the service sector also comprise other types of innovation than technological innovations, such as organizational innovations.' (European Commission: 2003, 121)

This confirms a study from Statistics Canada which argues that '…R&D in the services sector is not always technological in nature, as it may have a social character' (Statistics Canada: 2004, 11). In fact, according to this bulletin, it is likely that R&D activities in the services sector are underestimated. In parallel we can add that innovation in services "…is not on the natural sciences but more on the social sciences and humanities (SSH)". (OECD: 2001a, 9).

Moreover, the European Union's report, on the basis of the Second Community Innovation Survey (CIS II), provides evidence that "…only 7% of the innovating service companies surveyed had applied for a patent on at least one occasion. In the manufacturing sector, 25% of the innovators surveyed had submitted patent applications…" (European Commission: 2003, 408).

Hipp and Grupp (2005), considering these difficulties, maintain that trademarks could be a new empirical measure for service innovations. They base their argument on the results of the exploitation of a database. Looking at the number of national trademark applications in Germany, they found that it had increased massively and this would be due to the strong growth of service brands. Moreover, it seems that trademarks combining a product with a service are growing considerably and this blurs the definition of the service sector. On this basis, these authors conclude that using trademark statistics to investigate innovation in service sectors can be very helpful.

3.3.4 Firm Strategies

Firms' decisions to invest in R&D are part of a broader strategy at the firm level which includes, amongst others, deciding to invest in machinery and equipment, buildings and structures. According to Harris (2005, 13), these strategies are simultaneous so that examining machinery and equipment indicators should give us a great amount of information about innovativeness at the firm level.

Similarly, some researchers involved in business management have pointed in the direction of business strategy to explain some of the weaknesses in innovation investment in Canada.

Using the Current Competitiveness Index developed by the World Economic Forum, it is possible to observe that Canada ranks poorly in these indices relative to its current prosperity level (Martin: 2002). It reveals, according to him, a picture where firms, despite being in a context of high supply of innovative capacity (that is, many science and engineering graduates) exhibit a low demand for innovation (Martin: 2002). This is interesting as it confirms some research findings according to which management and more precisely commercialization expertise is weak in Canada. As stated in the Institute for Competitiveness & Prosperity's report, "Fewer of our managers have university degrees – 31 percent in Canada versus 50 percent in the United States" (2006, 30). If looking at educational attainment is important for adult population in general, an assessment of managers' skills would be quite relevant to understand the lag Canadian firms exhibit in different stages of the innovation process. We must remember that commercialization is an important step in the innovation process. The skills of managers are still more important today as they are likely to require a good knowledge of the international arena, etc.

Thus, as mentioned in the second section, skills in general, and skills of managers involved in the management of science and technology in particular, especially at the commercialization stage, are very important indicators of why firms invest or not in innovation, and whether it is in R&D or other sources of innovation. Moreover, examining business strategy of firms as a whole could reveal why firms exhibit a low level of innovation. This is at least what business management specialists suggest. To be sure, innovation surveys can be quite useful in this exercise.

To conclude this section on the most relevant indicators at the firm level, it is worth mentioning that standard indicators such as R&D are useful. Patents data at the firm level from national or international databases can also reveal very interesting information as explained in the second part of this paper. Stated precisely, patents at the firm level can be used to sketch technological trajectories over time. They can also give much information about the diversification strategy of a firm based on technological synergies. Finally, a look at patents and their assignees allows viewing the inter-firm mobility of its most productive engineers and scientists. However, as usual, it is important to exercise caution when patent data are used as not all firms will patent and not all inventions are patentable. In the second section, we also introduce *literature-based innovation output* (LBIO) indicators which could be used when firms do not patent. An important concluding remark would be that, once again, it is crucial to compare firms in the same industrial branch if a specific indicator is used, as their technological trajectories differ considerably from one sector to another.

<u>PART IV</u>: BEST PRACTICES FOR MEASURING INNOVATIVENESS

Based upon the review of literature and on the variety of indicators introduced in this report, we propose some ‘keystones’ to consider in the measurement of innovativeness. No single indicator is a magic formula to carefully benchmark innovation. Innovation is a complex phenomenon and varies across sectors and countries. To grasp its complexity, the best strategy is to try to understand how it evolves, that is, how it is induced, what the differences and similarities in patterns of innovation production and use are, and their economic and technological impact. As stated by Nelson, "Institutional change, like technological change, must be understood as an evolutionary process" (Nelson: 2000, 4). We propose three complementary avenues to follow in a benchmarking exercise without which it would be impossible to suggest relevant indicators.

4.1 A Need for a Broader and Systemic Measurement Framework

First of all, it is important to say that a conceptual framework upon which to base the development of benchmarks is an a priori of measuring innovativeness. Comparing differentiating elements involved in the success or failure of national innovation requires a profound comprehension of the way innovation progresses or stagnates. This paper has reviewed some of the literature on scientific and technological innovation at the aggregate, industrial dynamic and micro level that emphasizes the evolutionary tradition in economics and business management. This tradition has become increasingly influential even in mainstream economics. Using and even developing indicators of innovation would require paying special attention to this economics literature as it would allow understanding the relevance of benchmarking indicators.

4.1.1 <u>Composite Indicators</u>

Innovation is a multidimensional process. An important component of measurement is to grasp a series of indicators reflecting all these dimensions. However, the innovation process is actually difficult to capture on the basis of available indicators. We have presented three composite indexes in this report at the aggregate level. It is well beyond the scope of the present report to assess these composites but it would be a first step before undertaking a serious benchmarking exercise at an aggregate level. A systematic assessment of some composite indicators should be made taking into account all the underlying indicators included. We examined three of these indicators and they seem to have great potential at an aggregate level. However, it would be worth examining several of these indicators very closely following these steps, i.e. examining:

- The theoretical background supporting the development of this composite. This framework is important as it would allow testing the findings against it;
- The relevance of the variables included;
- The standardization of these variables;
- The weighting of these variables;
- Sensitivity tests conducted to check whether the aggregation of sub-components introduced a bias to the composite;
- Comparison with other measures to test the causality relationships.

In addition, Freudenberg pointed out, "…the construction of composites suffers from many methodological difficulties with the result that they can be misleading and easily manipulated" (Freudenberg: 2003, 3). Composite indicators are valuable as a starting point for an analysis. They allow cross-national comparisons of country performance in a specific area such as innovation and are quite useful especially as a 'communication tool', and for further analytical purposes. However, they are not sufficient to understand why a country has a national performance below expectations. To study innovation capacity in a more systemic way would be meaningful. It is impossible to use composite indicators developed for the aggregate level and then apply them at a sectoral level. Any attempt to measure innovation at a sectoral level should start by examining the dynamics of inter-industry flows (Scherer: 1982). This is the suggested second avenue.

4.1.2 Classification of Innovation Patterns

We know that technology does not follow vertically integrated industrial sectors but flows across industrial branches. Industrial dynamics are indeed quite dependent on these technological flows. In other words, technological conditions – technological opportunities as well as appropriability capacity – and market conditions in a specific country influence the rate and direction of technological change and therefore influence the formation of sectoral patterns of innovation in a given country. Attempts have often been made to develop taxonomies of sectoral patterns of technological change in different countries in order to better understand which factors determine innovation. These attempts respond to a need for policy makers to develop innovation policies that are more relevant to the real needs of firms and therefore more efficient.

Taxonomic exercises are now possible due to the development of innovation surveys that provide a quantity of information not readily available until recently.
We propose to build such patterns of innovation on the basis of innovating and non-innovating firms[15]. This would include the following information making use

[15] We propose to draw heavily on Pavitt's taxonomy and to use as the basic unit of analysis not only the innovating firm but also the non-innovating firms. While this is

of the model provided by Pavitt's taxonomy (1984):

- Principal activities of firms (innovating as well as non-innovating firms);
- Determinants of technological trajectories: sources of technology (intra-firm, other firms, public infrastructure, etc) users' needs (price or performance sensitive) means of appropriating benefits (patents, secrecy, trademarks, marketing, advertising, design know-how, dynamic learning economies, etc.)
- Characteristics of technological trajectories: balance between product and process innovation (product, process, mixed), relative size of firms, intensity and direction of technological (low or high vertical, low or high concentric)

This taxonomy should include information not only on production but also on the use of technology. This is the 'systemic-ness' of the national technological capability which is addressed by this exercise. It goes much further than exercises aimed at designing a national system of innovation as was initiated by Lundvall (1992) and his followers in many countries.

Such a classification of firms aggregated into sectoral patterns of technological change would permit grasping specific information about the source of innovation, determinants, etc. This implies that indicators will be used considering sectoral differences in innovation patterns. This will, in turn, give precise information for developing policies that respond to the real incentives required by firms to innovate.

The ultimate purpose of such a taxonomy would be to produce different scoreboards for each category of firms sharing similarities in the innovation process, that is, sources of innovation (suppliers, users, in-house, basic research, etc.) location of in-house competencies (R&D laboratories, production engineering departments, design offices, etc.), objectives of innovation (product innovation, process innovation or both). (Patel: undated)

4.1.3 Development of Innovation Skills Indicators

One important missing link in the measurement of innovative capacity is related to innovation skills. The OECD, with the support of some nation-states, developed the International Adult Literacy Survey (IALS), aimed at measuring skills directly. There has therefore been an effort to quantify human capital stock in the same way that physical capital has been measured. As a result, the true competency of people has been approximated in terms of skill levels, and human capital contribution to growth has been better understood. Hence, the failure to

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different from Pavitt's (1984) original taxonomy, it can be explained by the fact that when he developed his taxonomy there was a shortage of adequate data.

give due attention to other forms of learning was overcome, contributing to a better measure of human capital accumulation. Grasping the outcome of learning through a direct measure of skills made it possible for the impact of other forms of learning to be added to human capital measurement. Although this attempt to measure skills and especially literacy and numeracy skills is an important development, we still do not really know which skills are conducive to innovation. A recent update of the International Adult Literacy Survey (IALS), the Adult Literacy and Life Skills Survey (ALLS), explores the relationship between skills and Information and Communication Technology (ICT) use and familiarity. But this initiative is far from reflecting the whole set of innovation skills. A recent report of the Conference Board of Canada also pointed out the absence of innovation skills information and urged that we "identify the links between skills and innovation: There is a need to understand how innovation skills relate to academic achievement and to explore other ways to make a direct connection between skills and innovation. In particular, Canada needs to put systems in place for identifying, developing and promoting innovation skills" (Conference Board of Canada: 2004, 46). This will be our third avenue for a benchmarking exercise.

5. Conclusion

Measuring innovation is not an easy matter but it is essential in order to guide policy makers and business managers. Fierce competition from fast followers, often low wage countries, that position themselves as rapid imitators in global markets and the emergence of nations becoming innovators require an increasing commitment to innovation from large and small countries to retain their place in the race or to improve in relative terms. However, comparing the performance of countries (or firms), in terms of innovation, requires indicators which, taken in isolation, are not very meaningful. The problem is complex since we must determine what we want to measure, at which level we want to set the comparison and, more fundamentally, what we mean by innovation.

It has been seen in this report that there are standard indicators and less standard ones. Each one has its strengths and weaknesses and measures either the downstream or upstream of innovation. Some indicators are more appropriate than others, depending on the stage of innovation, the country, the nature and classes of the firm, the industrial sector, the fields of technology.

Composite indicators seem to have attracted more attention, and lately, many new indicators have been developed. We have seen that these indicators have important shortcomings and some are more credible than others. Methodologies that are used to weigh their components are fundamentally important while time series and comparable data are rather difficult to obtain for all countries. However, we consider that this is an important avenue to exploit as innovation is multidimensional, its determinants appear from many sources, and its impacts are felt in many sectors of the economy.

To prevent false usage of statistics in comparative studies of innovation systems, Katz (2006) proposed normalizing for size performance indicators derived from the ratio of two measures using the scaling correlation between the numerator and denominator. These scaling correlations are a very promising avenue for developing indicators thus allowing better comparative analyses between innovation systems.

The nature of innovation differs tremendously from one industrial sector to another and innovative activities are very heterogeneous at the firm level. This variety in the innovation reality is not easy to grasp and comparing sectors and firms innovative capability remains a challenge. However, many attempts have been made to improve indicators making it possible to compare and measure innovative efforts as much at the firm and industrial as at national and international levels.

In this report, an attempt has been made to point out the most commonly used as well as the newly developed indicators along with a mention of their respective strengths and weaknesses. What can be concluded for now is that there is no sole, unique indicator enabling us to better understand the innovation reality and advise policy makers on the incentives which would allow countries and firms to better perform. The challenge now is to comprehend better the dynamics of innovation. Indicators too often depict a static image of a phenomenon but technology changes and a solid understanding of how technology progresses or stagnates is required in order to design the right innovation policy. This exploration should be guided by 'appreciative theorizing', that is, theorizing that is relatively close to the empirical subject matter (Nelson: 2005) and in this context evolutionary economics would be quite appropriate.

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ANNEX A

Overview of empirical taxonomies of patterns of innovation

Author	Relevant dimensions and variables	Data source and sample	Industry classification	Method
Pavitt (1984), extended in Tidd et al. (2001)	• Sources of technology: R&D, design, suppliers, users, public science • Type of user: price or quality sensitive • Means of appropriation: patents, IPR, secrecy, etc. • Objective: cost-cutting or product design • Nature of innovation: ratio of product on process innovation • Firm size • Rate and direction of technological diversification	• SPRU Innovation survey • 2,000 significant innovations in Great Britain (1945-1983) • Dominance of large firms (53% with more than 10,000 employees, 25% with less than 1000)	Manufacturing and services: (1) science-based, (2) scale intensive, (3) specialised suppliers, (4) supplier dominated. Extended in Tidd et al (2001) with a fifth category: (5) information intensive	• Sector-level • Quantitative and qualitative analysis
Archibugi et al (1991)	• Innovation intensity: share of innovators; share innovation sales; ratio of internal on external sources of knowledge • Nature of innovation: ratio product on process innovation • Sources of knowledge: design; R&D; patents; capital embodied. • Firm size: average size and concentration index of innovators	• CNR-ISTAT innovation survey 1987 • 16,700 Italian firms, with more than 20 employees	Manufacturing: (1) traditional consumer goods; (2) traditional intermediate goods; (3) specialised intermediate goods; (4) assembled mass-production; (5) R&D based	• Sector-level • Cut-off points in ratios of industry level indicators to the mean across industries
De Marchi et al (1996)	• Innovation intensity: R&D, design, patents • Nature of innovation: ratio of product on process innovation	• CNR-ISTAT innovation survey 1987 • 16,700 Italian firms, with more than 20 employees	Manufacturing: Pavitt's (1984) taxonomy	• Sector-level • Test of Pavitt's taxonomy based on predicted rankings across pre-assigned groups and ANOVA
Malerba & Orsenigo (1996)	• Firm size of patenting firms • Concentration • Persistence of innovation • Technological entry and exit (firms patenting for the first or last time)	• Patent activities in 7 industrialised countries • Institutions and firms excluding individual inventors	Manufacturing: 'Schumpeter Mark I' (entrepreneurial) and 'Schumpeter Mark II' (routinised)	• Technology-level • Factor analysis and cut-off points on factor scores
Hatzichronoglou (1997)	• Technology intensity: intensity of direct and indirect (embodied) R&D	• ANBERD STAN dataset • Sampling of small firms, varying across countries	Manufacturing: (1) high tech, (2) medium-high tech, (3) medium-low tech, (4) low tech	• Sector-level • Cut-off points of technology indicators
Arvanitis & Hollenstein (1998)	• Innovation intensity: inputs (R&D, design) and outputs (innovations' value and shares of innovative sales) • Sources of knowledge: other firms, institutions, universally accessible information and other inputs (machinery, licences, personnel)	• Swiss KOF-ETH innovation survey 1996 • 516 firms with more than 5 employees	Manufacturing: 5 clusters	• Firm level • Factor analysis and clustering
Evangelista (2000)	• Innovation intensity: innovation costs per employees, % innovators • Nature of innovation: ratio of product on process innovation • Type of innovation inputs: R&D, design, software, training,	• ISTAT-CNR innovation survey 1997 • 19,000 firms with more than 20 employees	Services: (1) technology users, (2) S&T based, (3) interactive and IT based; (4) technical consultancy.	• Sector-level • Factor analysis and clustering

Author	Relevant dimensions and variables	Data source and sample	Industry classification	Method
	machinery, marketing • Sources of information: internal (R&D lab) and external (other firms, institutions, etc) • Innovation strategies: objectives of innovation (market driven, efficiency, etc)			
Marsili (2001)	• Technological intensity • Technological entry barriers (share of innovative activity in large firms) • Persistence of innovation • Inter-firm diversity • Technological diversification • Sources of knowledge	• SPRU databases on innovative activities of large firms	Manufacturing: (1) science based, (2) fundamental processes, (3) complex systems, (4) product engineering, (5) continuous processes	• Sector-level • Qualitative and quantitative analysis
OECD (2001)	• Knowledge intensity: direct and indirect R&D expenditure; skill levels.	• ANBERD STAN dataset • Sampling of small firms, varying across countries	Manufacturing and services: (1) high-tech manufacturing, (2) low-tech manufacturing, (3) knowledge intensive services, (4) traditional services	• Sector-level • Cut-off points of indicators
Peneder (2002)	• Input intensity: labour; capital; advertising sales ratio; R&D sales ratio.	• Expenditure by investment category in US firms •	Manufacturing: (1) technology-driven, (2) capital intensive, (3) marketing driven, (4) labour intensive, (5) mainstream manufacturing.	• Sector-level (3 digit) • Factor analysis and clustering
Raymond et al (2004)	• Model of innovative behaviour: Estimated effects of firm-level and industry-level characteristics on the decision to innovate and the returns to innovation.	• Manufacturing firms with more than 10 employees in the Netherlands • CIS-2, CIS-2.5 and CIS-3	Manufacturing: (1) high-tech, (2) low-tech, (3) wood industry.	• Econometric model at the firm level with industry-specific coefficients

Source: De Jong, J.P.J and Orietta Marsili (2005)

ANNEX B

FIGURE 1

Table 5
Sectoral technological trajectories: Determinants, directions and measured characteristics

Category of firm		Typical core sectors	Determinants of technological trajectories: Sources of technology	Type of user	Means of appropriation	Technological trajectories	Measured characteristics: Source of process technology	Relative balance between product and process innovation	Relative size of innovating firms	Intensity and direction of technological diversification
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Supplier dominated		Agriculture; housing; private services traditional manufacture	Suppliers Research extension services; big users	Price sensitive	Non-technical (e.g. trademarks, marketing, advertising, aesthetic design)	Cost-cutting	Suppliers	Process	Small	Low vertical
Production intensive	Scale intensive	Bulk materials (steel, glass); assembly (consumer durables & autos)	PE suppliers: R&D	Price sensitive	Process secrecy and know-how; technical lags; patents; dynamic learning economies;	Cost-cutting (product design)	In-house; suppliers	Process	Large	High vertical
	Specialised suppliers	Machinery; instruments	Design and development users	Performance sensitive	design know-how; knowledge of users; patents	Product design	In-house; customers	Product	Small	Low concentric
Science based		Electronics/ electrical; chemicals	R&D Public science; PE	Mixed	R&D know-how; patents; process secrecy and know-how; dynamic learning economies	Mixed	In-house; suppliers	Mixed	Large	Low vertical / High concentric

* PE = Production Engineering Department.

Source: Pavitt (1984)