WHAT INDICATORS FOR SCIENCE, TECHNOLOGY AND INNOVATION POLICIES IN THE 21ST CENTURY?

BLUE SKY II FORUM – BACKGROUND [1]

I. Introduction

1. It has been long understood that the generation, exploitation and diffusion of knowledge are fundamental to economic growth, development and the well being of nations. The widespread diffusion of new information technologies in the 1990s vastly improved the capability of generating, manipulating, and distilling information so that it becomes knowledge, bringing the issue of how knowledge is created, nurtured and used for competitive advantage into the foreground. Central to this is the need for better measures of science, technology and innovation. The Science and Technology Ministerial in 2004 confirmed the need "to develop a new generation of indicators which can measure innovative performance and other related output of a knowledge-based economy" with special attention to "the data required for the assessment, monitoring and policy making purposes". Beyond the promotion of the appropriate environment for invention, diffusion and commercialisation of scientific outputs, which has been the preoccupation of many Ministries of Industry or Science & Technology, there is also a growing interest from Central Bankers and Ministries of Finance who want to better understand how innovation creates value in the form of productivity, profits, contributes to the valuation of enterprises, and ultimately leads to growth, productivity, and competitiveness of economies.

2. The OECD has worked for nearly 50 years to develop indicators and policy analysis of science, technology and innovation. Over time the nature of science, technology and innovation has changed, and so has the need for indicators to capture these processes and their interplay. Innovation has increasingly become a collective endeavour in a global market, it has evolved in new non-technological forms, and its diffusion is more rapid thanks to new information technologies. Science is increasingly becoming multidisciplinary and based on networking and knowledge transfers, hence science systems need to respond better to a more diverse set of stakeholders (OECD, 2004*a*). While new challenges at the interface between science systems, industrial innovation, human resources and knowledge flows need to be addressed, the existing statistical measures are often inadequate for analysing those linkages and the dynamics of science, technology and innovation, especially in an increasingly globalised world.

3. This paper examines past and current efforts to measure science, technology and innovation indicators, how the role of these indicators has changed and identifies new paths that could be explored. The eight themes presented in Section V of the paper provide a basis for organising the discussion at the forthcoming *Blue Sky II* conference on the next generation of Science, Technology and Innovation indicators (STI) to be organised in Canada, September 25-27, 2006 (see Annex I). While *Blue sky* is a synonym for thinking creatively, without limiting horizons, about developing new indicators to respond to changing policy and user needs in the STI area, resources available to develop new indicators might be

[1]. This draft, written by Alessandra Colecchia (OECD) is based on Arundel, Colecchia and Wyckoff (2005) and has benefited from comments of colleagues and members of the Steering Group for the Blue Sky II Conference.

limited and require selective efforts. Nonetheless, there is also scope for creative use of existing data and for leveraging work in statistical fields other than the STI one. A balance needs to be struck between developing the new and rethinking the old.

Box 1 - S&T indicators at OECD: a brief history

Almost 50 years ago, in 1957, an *ad hoc* group of experts met to discuss methodological problems of surveys of research and experimental development expenditure. In 1961 the OECD was formed and the Directorate for Scientific Affairs held a conference in 1962 to more systematically address the problems of measuring R&D – the first "blue sky" S&T indicators conference dedicated to developing new indicators to serve S&T policy formulation.

Christopher Freeman and Alison Young were commissioned as consultants to write a background document for that meeting, "Proposed Standard Practice for Surveys of Research and Development," that was subsequently discussed, revised and accepted by experts meeting in Frascati Italy in 1963. Since then, the so-called Frascati Manual has been revised and expanded 5 times (1970, 1976, 1981, 1994, and 2002).

In some ways, these early pioneers were too successful. Of all the S&T indicators, R&D and constructed indicators such as the R&D intensity of a country (R&D/GDP), are by far the most popular and have now been enshrined in specific S&T policies as quantifiable targets. This interest persists notwithstanding the fact that the weaknesses of this indicator are well-known, most notably that it measures only one type of S&T input (R&D) within a complex system of different innovation inputs and outputs.

The success of the Frascati Manual and R&D indicators led to the creation of a series of similar methodological and statistical efforts in other areas with the goal of better describing the broader innovation system. While this constellation of methodological guidelines and statistical efforts is collectively referred to as the "Frascati Family", in fact none of them has achieved the prominence of the parent Frascati and R&D indicators. Many reasons exist for why this is the case, including insufficient time to understand and exploit new data sources on innovative activities.

Perhaps more importantly, there was an ambivalent political mandate in support of new indicators. This began to change in the mid-1990s when OECD Science Ministers meeting in Paris requested that the OECD launch a "New S&T Indicators" project. Dubbed the "blue sky indicators" project, its objective was to think creatively, without limiting horizons, about developing new indicators to better serve policy needs. Ministers asked member countries *"…to collaborate to develop a new generation of indicators which can measure innovative performance and other related output of the knowledge-based economy."* The challenge was to propose new indicators that would shed light on the broader system of innovation, including outputs of this activity.

The kick-off conference in 1996 drew together nearly 200 researchers, academics, statisticians and policy makers and focused on a wide range of indicators: intangible investment, patents, bibliometrics, measures of innovation through direct surveys, globalisation and surveys of firm performance. It occurred at the end of a major transition in theories about innovation policy and economics. The shift in thinking was from a linear model in which innovation is fed by R&D (as illustrated by the first Frascati Manual) towards a systemic theory of innovation where many different types of knowledge flows play key roles in firm-level innovative capabilities (as captured by the first Oslo Manual). The conference provided an opportunity for a wide range of researchers to summarize their work based on a systemic approach to innovation, as well as empirical work using the initial results of the first Community Innovation Survey in Europe or data sources such as patents and bibliometrics to explore linkages between firms. Very few contributions were forward-looking, in the sense of evaluating the possibilities for constructing new indicators for emerging policy needs.

The lack of forward-looking indicator research reflected to some degree the consensus that the structural framework for S&T was likely to remain stable for the foreseeable future. This was based on an acceptance of innovation as a major source of comparative advantage for developed countries, in part influenced by mainstream growth theory the early 1990s.

The conference gave birth to a number of proposed follow-up activities: (i) improve the understanding of the mobility of human resources for science and technology; (ii) track the circulation of disembodied knowledge and assess the economic value of innovation though use of patent statistics; (iii) trace the activities and networks of the science system through bibliometrics; (iv) look in depth at the innovative activity of a few select service activities; (v) study the innovation process at a firm-level, particularly for small firms; (vi) measure the internationalisation of S&T activities through use of data on the activities of multinational enterprises (MNEs) and patent data; (vii) construct indicators for specific S&T policies such as the generosity of R&D tax credits (see OECD 2001*a*).

II. The Blue Sky I experience and beyond

4. The first "Blue Sky" or “New S&T indicators” activity was launched in 1996 by the NESTI following a request by ministers (see Box 1). Nearly every one of the proposed activities was followed-up and has evolved into a larger body of work at the international level. The major exception has been bibliometrics, which remains more of an academic interest, although a number of individual government agencies have been active in this area. Work on the mobility of human resources for science and technology has focused mainly on internal, domestic mobility between institutions and has been limited by the availability of data and the inherent constraints of coverage of labour force surveys and timeliness of census data. The use of patent statistics to look at various aspects of the innovation system has progressed considerably, especially the construction of indicators that allow international comparisons. A series of initiatives have been launched to better understand and measure innovation in the service sector including the 1997 revision of the Oslo Manual to provide guidelines for measuring innovation activities in services, the 2002 revision of the Frascati manual, in-depth work on the health sector (Young, 2001) and series of case studies on knowledge-intensive services. Surveys of innovation, best exemplified by the European Union’s Community Innovation Survey (CIS), continue to evolve and provide new insights, especially when the data are analysed at the firm-level. Lastly the construction of indicators for R&D tax provisions across OECD member countries has been updated and refined several times and is a regular indicator in publications like the *STI Scoreboard* (OECD, 2003*a*).

5. The work on new indicators launched in 1996 was a valuable endeavour that generated a number of important advances. Through this work, some important lessons were learned about developing new S&T indicators. The first lesson is that not all ideas can, or should, be developed and implemented, especially in the current context of limited budgets for statistical agencies and an environment where government activities are increasingly held to high standards of accountability. The second is that S&T indicators are not the sole province of those working in the S&T area. In fact, some of the more path breaking work during the 1990s occurred outside the direct S&T indicators community, in the areas of:

- Information society statistics: the information society was given high priority at the end of the 90s and, over the course of about 5 years, international definitions were established, in-depth measurement of some key applications like e-commerce was launched and a decision was reached to capitalise ICT intangibles like software as a fixed asset within the systems of national accounts.

- Multinational enterprises (MNEs) statistics: in order to understand the role played by MNEs in the economy a data series was developed based on the *activities* of foreign affiliates and their parents as opposed to the more traditional view of measuring *investment* flows through Foreign Direct Investment (FDI). Akin to structural business statistics, a focus on activities allows for the measurement of MNE R&D, which constitutes a large portion of business enterprise R&D. Work on developing a set of methodological recommendations on how to measure various aspects of economic globalisation was initiated, resulting in a handbook on the subject in 2005 (OECD, 2005).

- Education statistics: work has been carried out to improve the quality and availability of internationally comparable education statistics. The *OECD Education Database* provides comparative information on key aspects of education systems and covers enrolment rates, graduate and new entrants by sex, age and level of education, teaching staff and expenditure. The *Educational Attainment Database*, provides data on educational attainment of population broken down by gender, age and employment status (employed, unemployed or inactive). A new instrument to assess knowledge and skills has been launched in 2000 with the Programme on

International Student Assessment (PISA), a three-yearly survey of 15-year olds in OECD and non-member economies (see http://www.pisa.oecd.org/).

- Productivity estimates: fundamental work to improve international comparability of productivity estimates was made through the development of a manual that set out methodological recommendations as well as the necessary data requirements to calculate productivity measures (OECD, 2001*b*). Work was launched to explore how to improve the measurement of output in hard to measure areas like services and development of price indexes that better accounted for technology-induced quality changes in products like computers (Triplett, 2004).

6. From the above examples, it appears to be evident that efforts are needed to combine data sources that go beyond those in the traditional S&T area to provide an integrated view of the knowledge base and knowledge flows.

III. Thinking ahead: the New Millennium

7. While science and technology, especially new information technologies, were a key determinant of growth performance across countries in the 1990s, with the advent of the new millennium broader trends have become apparent and create a new context for STI indicators. In particular, new measurement challenges come from changes due to globalisation, demography and the environment, including the demand and supply for natural resources. The first trend consists of major shifts in the location of comparative advantage for the production of both manufactured goods and services. China, the new 'workshop of the world', accounts for a growing share of manufactures while India is developing strengths in services such as software development, clinical trials, and call centers. Along with the enlargement of the European Union to include many of the transition economies, there has been a consequent increase in the "off-shoring" of manufacturing and service production from high wage to low wage countries.

8. Neither outsourcing nor off-shoring are new – both have been underway for decades. The difference today is that high-wage countries may no longer be able to maintain comparative advantage in the face of low-wage competition through 'continual innovation', as suggested by Romer – at least not through a narrow view of innovation defined as new products and processes in high technology sectors[2]. This is because the innovative capabilities of lower-wage, larger-markets and countries endowed with highly-skilled human resources, such as India and China are rapidly increasing, as shown by OECD data on the growth of R&D and engineering graduates in China, or anecdotal stories on the ability of both India and China to compete not only in low value-added sectors such as textiles, but also in knowledge intensive sectors such as software, capital goods and ICT manufacturing[3].

9. The second major structural change in developed economies is a demographic increase in the average age that could adversely affect the demand for innovative products. Research consistently shows that the adoption rates for innovative consumer products and services, such as mobile telephones and Internet access, is inversely proportional to age and positively correlated with income. As an example, in 2000, 90% of Italians between the age of 15 and 24 had a mobile phone, compared to only 30% of Italians over the age of 55[4]. Such demographic change could reduce aggregate domestic demand for innovative products and, secondarily, in so far as a sophisticated domestic market plays a role in national innovative

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2. See Romer and Luis Rivera-Batiz (1991).

3. See Engardio P. and Roberts D., 2004.

4. EURESCOM, 2001.

capabilities, an ageing population could reduce the innovative capabilities of the home market[5]. On the other hand, an ageing population might have a positive impact on the demand for technologies and innovative products related to health or leisure services.

10. The third global change includes major technological shifts, with a new shift possibly underway due to a rapid increase in the demand for energy. While worries about limits to oil supplies have existed for some time, the growing demand from China and India coupled with continued instability in the Middle East brings these assertions to the foreground. Perhaps more significant is the better understanding of how the consumption of carbon-based fuels are changing our climate. Both trends are open to criticism, but when the two trends are combined, it becomes clear that science and technology will have to address the need for a conversion from carbon-based fuels to other sources of energy and/or methods such as carbon sequestration to minimise the release of carbon dioxide into the atmosphere.

11. These large, long-term trends underscore the need for a more forward-looking approach to S&T indicators that can meet policy requirements over the short and medium term future.

IV. Taking into account the changing nature of science, technology and innovation

12. The rapid diffusion of new information technologies and the increased globalisation of markets have contributed to changing the nature of science and innovation and the linkages or interface between the two areas. Understanding the nature of these changes will help to address the need for new indicators in science, technology and innovation. This section outlines some of these changes.

The science-innovation interface: industry-science linkages and multidisciplinarity in research

13. Although an important share of innovative activities is not directly science-based, there is clear evidence that public research is playing a key role in the development of new technologies in areas such as ICT, biotechnology and nanotechnology, and thereby contributing to major innovations. In some fields academic and industrial research are converging. Much of the work in large industrial research laboratories and in small, high-technology start-ups is at the cutting edge of the research frontier. On the other hand academic scientists often explore the commercial applications of their discoveries. An example is the branch of biology known as structural genomics, in which the academic and industrial communities have launched initiatives almost simultaneously (OECD 2004*a*).

14. The linkages between public scientific research and industrial innovation show up in funding patterns. Governments are increasingly funding R&D performed in the business sector, likewise business funds a growing share of the R&D performed in the higher education and government sectors. What is more spectacular in industry-science linkages is the emergence of broad alliances between Universities and firms and the growing commercialization of research results through spin-off companies and the licensing of intellectual property (OECD, 2004a).

Innovation has increasingly become a collective endeavour

15. Innovation became more market-driven, more rapid and intense, and more closely linked to scientific progress during the 1990s. The cost of performing innovation is changing. On the one hand, as the range of technologies required for innovation has expanded, innovation has become more complex, while information technologies have driven down the cost of experimentation. The final impact on the

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[5]. This is one of the four main points of Porter's diamond for national innovative capability (Porter, 1990). However, there is little empirical evidence to support the role of sophisticated domestic consumers, aside from a few case studies that suffer from a selection bias. For the latter, see Beise (2001).

costs and risks of innovation is uncertain. On the other hand, factors linked to globalisation have reduced the cost of research collaboration and the cost of outsourcing key components. In response to both developments, firms have become more specialised, relying on co-operation among participants in different fields of expertise. This strategy can reduce uncertainty, share costs and knowledge, and bring innovative products and services more quickly to the market.

16. Companies must reconfigure their business model to seek new ways of profiting from innovation. One option is for various actors – businesses, government agencies, universities – to improve the productivity of innovation: increasing outputs and results while reducing the costs. This has forced innovation out of stand-alone central labs and into a greater dependence on linkages such as networks, alliances and formal and informal relations, all of which are more characteristic of the non-linear model of innovation. The development of such linkages could be producing basic structural changes that improve research productivity and allow innovation systems to adapt to new conditions. The much-cited innovative cluster of Silicon Valley is the most visible expression of strong innovation dynamics that can emerge from the evolution of linkages between dominant innovative firms (*e.g.* Fairchild), government funding agencies (*e.g.* DARPA), the geographical interaction of young firms, an outward-oriented university system, new forms of intermediaries like venture capitalists and "angels," and the formation of strategic partnerships between firms manifested in alliances, patent licensing, and patent pools. Tracking and understanding these dynamics are important for forging policy that supports this experimentation while retaining a competitive environment.

The location where the value of innovation is created and captured is changing

17. Another trend, driven by new information technologies, is the growing importance of user-centred innovation. Advances in computer hardware and software make possible it to outsource custom design to users (via innovation toolkits), while the ability of individual users to combine and coordinate their innovation-related efforts is improved by new communication media such as the Internet (von Hippel, 2004).[6]

18. Geographical location is also changing. Multinational enterprises (MNEs) are gaining importance as actors in the innovation process.[7] Zysman (2004) argues that globalisation has been partly driven by increasing modularisation of standard components in some industries and that some types of R&D are becoming a globally-sourced commodity. Under these conditions, innovative firms rely on cross-national production networks and create value from the efficient use of global supply chains. While it is clear that MNEs are important actors in the innovation process, their role is poorly understood, partly because the

6. A clear example applies to the semiconductor industry were recent technology – integrated circuits called field programmable logic devices (FPLDs) - enable the customer to become both the designer and the manufacturer. Suppliers pre-fabricate these chips and sell them to customers who use their design and simulation software and equipment to program chips for themselves. Suppliers do not need to be involved in the design process and physical prototypes can be prepared by customers at little cost or time (von Hippel, 2005).

7. MNEs account for a dominant share of OECD business enterprise R&D. Ten large firms account for about one-quarter of all US business enterprise R&D (IRI, 2000). In Sweden, the R&D expenditures of Ericsson were equivalent to almost 60% of Sweden's BERD in 1999, although some of this R&D was performed elsewhere in Europe, Asia and North America (Ericsson 2001). In Finland, Nokia was responsible for performing approximately one-third of Finnish BERD in 1999, and Nokia's global R&D expenditures were equivalent to more than 80% of Finnish BERD in 2001, although an estimated 40% of this funding was invested in foreign R&D centres (Ali-Yrkkö *et al.* 2000). In Canada, the R&D expenditures of Nortel Networks were equivalent to more than one-third of Canadian BERD in 2001, although the company's R&D was conducted in more than 10 countries, including Australia, China, France, the UK and the US, in addition to Canada (see http://www.nortelnetworks.com/corporate/technology/innovation/randd.html).

overview of national governments and their various agencies are limited by the political boundaries of the country. This can limit statistics on MNEs to the national country, creating a partial view of their global innovation activities.

Human resources in science and technology at the heart of the innovation process

19. At the heart of an innovation-led economy is the need for people who innovate. As demand for this cadre of talent increases and as innovative networks increasingly cross borders, this segment of the labour force has become increasingly global. Key ports of entry for this flow are universities. The United States, Australia, the United Kingdom and Switzerland are able to attract foreign students to their universities who in many cases stay on and become researchers. Likewise, the migration of the highly-skilled has become an important source of talent for countries like the United States who were able to sustain the fast growth from a relatively narrow and specialized part of the economy, like ICT production and software development, without hitting inflationary bottlenecks by attracting hundreds of thousands of skilled professionals. This was based both on a large input of tertiary students who then remained in the United States after completing an advanced degree and on a visa system that favored the highly skilled. The issue of "brain drain" and "brain gain" rose in prominence and was the focus of a 2001 Conference at the OECD[8]. What arose from that conference was that the international mobility of the highly skilled was more than a simple win-lose, zero-sum equation but rather a complex and variegated phenomenon that is better characterized as "brain circulation". The push and pull factors that influence these movements are a useful diagnostic of the strengths and weaknesses of the overall national system of innovation.

20. The ability of OECD countries to attract and compete for students in the global market might decline in the future and more effort might be needed to increase countries' indigenous supply of tertiary students and new doctorates.[9] This, coupled with the emergence of quantitative goals targeted at improving the innovation system of various countries and regions, such as the objectives set out at the Lisbon and Barcelona Summits of the European Union, requires better data on the mechanism to produce researchers. Concurrent with this are demographic challenges facing most of the OECD as our populations age and as the attractiveness of science to the young wanes. These and other developments indicate that we need better indicators on the demographics of skills by age and gender and among immigrant and non-immigrant populations. The goal is to reverse the current declining interest in science among students that has been observed in many OECD countries, which will be of crucial importance if growing opportunities for the highly skilled in the 'donor' countries (India and China, etc) reduce the ability of high-income countries to source talent from abroad. An increase in the indigenous supply of scientists and engineers may depend on greater success in attracting large under-represented groups, such as women, to pursue science and engineering careers.

[8]. OECD Seminar on International Mobility of Highly Skilled Workers: From Statistical Analysis to the Formulation of Policies", Paris, 11-12 June 2001.

[9]. For example, the supply of PhD candidates to the United States from two major source regions, West Asia and East Asia (including China), peaked in 1996. The number from East Asia declined by 24% between 1996 and 2000, well before the additional visa restrictions in the United States after 2001. At the same time, the number of PhDs produced by China took off in 1996. It is possible for the two trends to be linked, with the decline in the flow of PhD students to the US from East Asia due to increasing opportunities at home. The UK has also reported a 5.3% decline in university applications for the fall of 2005 by students outside of the European Union (see UCAS, http://www.ucas.ac.uk/new/press/news170205/index.html).

V. Rethinking old indicators and developing new ones: some ideas and issues for discussion

21. While "blue sky" thinking is a useful exercise, it needs to be tempered by the reality that in most cases the resources available to develop new indicators are very limited. This necessitates a two-pronged approach: creative use of existing surveys and selected, targeted, new efforts. It also requires a networked approach that leverages work in statistical fields other than S&T indicators to provide a comprehensive view of innovation with minimal additional resources.

22. Below are a set of 8 themes around which the Blue Sky Call for Papers (see http://www.statcan.ca/english/conferences/sciencetech2005/index.htm) is organised. Examples of questions one might want to address, but does not need to be confined to, are proposed under each theme. The Forum in 2006 would provide a venue for a critical assessment of the current S&T taxonomies and metrics, in terms of their quality and usefulness to policy making, both in a national and international context. Ideally it would contribute to develop a framework for indicators that addresses some of the issues described under the different themes.

- **THEME 1. The Globalisation of research activities and networks**

Issues: the nature of R&D performers has changed (*e.g.* dominance of R&D by large, diversified multinationals, and trend of outsourcing of R&D to "R&D Services" firms, many of which, while classified in services, undertake R&D for manufacturing industries) and new ways of conducting R&D are emerging (*e.g.* conducting R&D in collaborative environments, using joint ventures and alliances and outsourcing R&D to foreign affiliates). Yet, the structure of data collection is tied to models of R&D performance that are increasingly unrepresentative of the whole of the R&D enterprise and new forms of conducting R&D are not well captured in present surveys (NRC, 2005).

Q: *What are the measurement priorities for R&D policy making in the 21st century? Is it the development of good measures of globalisation of R&D activities? Or the need for better exploiting microdata to analyse R&D at the disaggregated level, e.g. by activity, institution, region, firm size, field of research? This would help in identifying research-intensive clusters, provide information for prioritising public research investment or support schemes such as tax incentives or programmes. Finally, what about the measurement of R&D capital investment and of its impacts on growth and productivity (e.g. we are lacking internationally comparable price indexes for R&D and rates of depreciation; data on R&D imports and exports)?*

- **THEME 2. Understanding the changing nature of science and innovation and their impacts**

Issues: Science and innovation have increasingly become a collective endeavour and more closely linked. Science has become more multidisciplinary in nature. Industrial innovation has taken new, non technological forms. A lot of successful innovation comes from better managing organisations. For example linkages of business processes via information technologies play an important role in raising firm's productivity. Demand increasingly constitutes an important incentive or constraint in shaping the innovative activity. The challenge is to obtain measures of organisational forms that integrate different business functions throughout the entire value-added chain from the end consumer to suppliers. These chains can be particularly complex because they can span multiple firms or divisions of MNEs and cover the globe.

Q: *Do we have good measures of innovation activities in the public sector? Of the impact of publicly funded R&D? Of co-operation among actors and nations to support multidisciplinary research? Is there demand for indicators that track new forms of innovation (such as organisational innovation) and their linkages with new information technologies (e.g. e-business methods)? Is there value to projects exploiting innovation surveys microdata in a comparable way, by choosing the same* *tabulations and methodology and trying to answer the same questions about the linkages between innovation inputs and outcomes?*

- **THEME 3. Capturing the value of research and innovation**

Issues: The location where the value of research and innovation is created and captured is changing. Firms are increasingly relying on external sources of knowledge rather than in-house research, and research (including public research) is increasingly commercialised via spin-off companies and the licensing of patented technologies (OECD, 2004*a*). There is need to develop indicators that capture the value of innovation and answer questions such as who is appropriating the returns from innovation.

Q: *Innovation surveys could be exploited to develop new indicators on the extent of protection granted to innovation (via patents, trademarks, copyright, secrecy, etc.), on the types of investments complementary to R&D that are necessary for innovation to occur, or develop proxies that capture the value of innovations. Are these avenues of research worth exploring? Are indicators based on patent data proving to be useful for policy making? Should the possibility of developing other internationally comparable indicators based on intellectual property registration systems, such as copyright, industrial design, and trademarks, be investigated? And what about indicators of private-public research partnerships and forms of commercialisation of research results (such as spin-off companies or licensing agreements)?*

- **THEME 4: Human resources in science and technology (HRST) and global knowledge flows**

Issues: Looking at demand and supply of human resources for science and technology and their mismatch is a complex exercise and requires the availability of a large range of good quality data. Demographic factors and education systems influence the long term supply of S&T skills. Behind those supply numbers are individual's decisions to choose S&T careers, which in turn will be a function of perspective wages, employment opportunities and quality of jobs as opposed to those in other areas. Also the availability and use of "on the job" education and training schemes, formal and informal, influence the available pool of skills at any given moment in time. The demand for HRST workers will depend on the industrial specialisation of a country, with the growth of sectors relatively more intensive of S&T skills driving the demand for those skills. It will also depend on the diffusion of skill-biased general-purpose technologies, such as new information technologies, biotechnologies, nanotechnologies, whose use is complementary to the availability of a specialised workforce. Finally it will depend on major shift in government spending on S&T related areas, *e.g.* defence, aerospace, health, new technologies, large scale science projects, and on how the S&T labour market reacts to these changes. The mobility of human resources complicates matters even further.

Q: *What are measurement priorities in this field? Improve the availability and quality of data on researchers, including their demographic characteristics (statistics broken down by age, gender, employment status, educational attainment, occupation and sector of origin of employment; data on wages, unemployment rates, job conditions in S&T occupation)? Work on how existing vehicles, such as Labour Force Surveys, can be adapted to respond to such needs? Collecting information on how institutional practices of supporting research affect the supply and demand for young researchers, on the impact of team production on scientific career paths, and on the employment practices of labs, to assess how government initiatives or other exogenous changes affect the S&T job market? Which approaches are best to trace the mobility of human resources for science and technology both between sectors of the economy and internationally? Finally, should the relative contribution of different skills to national innovation systems be measured and how? Perhaps with indicators of the distribution of talent (proxied by educational achievement) across different disciplines (multi-disciplinarity), occupations and within specific sectors?*

- **THEME 5. Building scientific knowledge capital**

Issues: Knowledge capital has been described as a form of intangible asset, i.e. hard to measure. Indeed scientific education, scientific training, knowledge networks (among researchers, university-industry knowledge transfers, public-private partnerships), clustering of research and innovation activities, all contribute to the building of economies' scientific knowledge capital, responsible for scientific discoveries and innovation. Although hard to measure with traditional STI indicators, indicators of scientific knowledge could be developed borrowing from other areas. For example from surveys of scientific literacy, from the literature on social capital, from bibliometric indicators of scientific publications.

Q: *Are internationally comparable measures of creation and diffusion of scientific knowledge useful for policy making? Are there examples of existing policy relevant indicators in this area? Are there examples of non S&T indicators and literature one could borrow from? Should these indicators be confined to measures of the stocks and flows of knowledge capital (or of some components) or also try to capture the economic and social impacts of scientific knowledge?*

- **THEME 6. Emerging, multidisciplinary STI fields: ICTs, biotechnology, nanotechnology, energy and resource extraction technology**

Issues: In the 1990s the combination of continually falling computer prices with vastly improved performance has led to the ubiquity of computing and communication, allowing a convergence of various systems (telephony, computing, broadcasting) into a seamless network, much of which is mobile, and embedded everywhere. The possibilities are only now beginning to be understood. Similar developments could occur in biotechnology, which has many applications not only in the pharmaceutical and agricultural sectors, but also in many industrial sectors where biotechnological processes could replace chemical or mechanical production systems. In more recent years scientists introduced nanotechnology, the engineering at the scale of atoms and molecules. This technology could lead to faster computing devices based on carbon nanotubes, miniature medical probes, and new types of lights and solar cells, as well as tremendous changes in the materials and drugs sectors. Finally there are signs that energy technology is going to make a dramatic leap forward, with the promise of efficient fuel cells, carbon sequestration technology, new approaches to solar power and safer nuclear plants

Q: *What indicators on these emerging STI fields are mostly needed? Indicators on the applications, uses and benefits of new technologies? Statistics to match the specific needs of selected sectors where new technologies are likely to have a large impact, such as agriculture, health, services and some industrial applications? Cross-countries comparisons of research efforts and outputs in "hot" research areas? Indicators of funding schemes or venture capital availability?*

- **THEME 7: The science and innovation landscape: regions, players and issues**

Issues: While increasingly relying on networks across actors and geographical locations, science and innovation activities also tend to cluster in particular locations or around certain institutions (e.g. a leading university or a research lab of a multinational corporation). Geographical boundaries and traditional units of analysis might not be the best to analyse the changing landscape in science, technology and innovation.

Q: *Is there a special need for indicators tailored to STI developments in developing countries, remote regions (such as polar regions), micro actors (e.g. specialised surveys for micro-enterprises). What indicators can be developed to map and track innovative clusters? Do we have good data and indicators to look at the role played by key players in knowledge creation and diffusion such as universities, research labs or MNCs? Do we need better data on international cooperation in the STI area and its links to sustainable development?*

- **THEME 8: New indicators for innovation policies?**

Issues: There are only a few internationally comparable indicators for investment in or the use of specific policies to support innovation. The available indicators are largely limited to R&D support, such as the amount of government investment in R&D and the OECD 'B index' for the rate of tax subsidies per unit of R&D by private firms. There are also very few indicators for specific areas of policy involvement, such as a range of programs to improve the innovative capacity of SMEs. There is need to identify indicators of innovation policy and design a systematic framework to address their development. Examples are new indicators that directly measure policy investment, the types of policies in use, their effectiveness, and their impacts and economic returns. This information would help to fine tune innovation policy instruments.

Q: *What new indicators would aid in formulating and assessing innovation policies in an internationally comparable way? Indicators of direct government support in areas other than R&D,, e.g. extending the "B index" type of indicator to include measures of tax treatment of other investments conducive to innovation (e.g. in the area of industrial design and process engineering, or training of human resources)? Indicators on the use of innovation support programs by firms or public institutions? Indicators on the purpose, outcomes, or cost to the firm of public-private partnership? Indicators on impacts of innovation policies, such as the number of spin-offs, patents, or licensing revenue created by public research institutions? Is research on the impact of innovative activity on policy goals such as improvements in the standard of living or quality of life needed? And what about the development of methodologies and indicators for result-oriented S&T budgeting and policy evaluation?*

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