

**Quality and Accountability in PSE Research:
The Measurement Challenge**

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Prepared for the Council of Ministers of Education, Canada
November, 1998

1.0 Introduction

Over the past decade, most industrial economies have begun the transition to knowledge-based economies, in which the production, use, and distribution of knowledge and information are critical for the process of innovation and economic growth. Current trends in information technologies and the development of global communications networks accentuate the importance of scientific knowledge for the future growth of the economy. The knowledge-based economy (KBE) highlights the production of knowledge in networked institutional settings, and the ability to distribute that knowledge to the relevant components of the innovation system. It is also a learning society that places a premium on the ability of individuals and organizations to absorb and use information (OECD, 1996).

Science and technology policy in Canada has placed increasing emphasis on the need to transform this country into a knowledge-based economy and society. While many factors will ultimately contribute to the success of this goal, the role of post-secondary institutions in generating new scientific knowledge and diffusing that knowledge to relevant actors in other parts of the economy is widely regarded as central. Closely related to this issue is the role that research performed in post-secondary education (PSE) institutions plays in the innovation process at the local and regional level. The ‘systems of innovation’ approach used in academic and policy studies highlights the interaction between different components of the innovation process (Edquist, 1997). In this approach, PSE research institutions form a critical part of the infrastructure that supports the innovation process. Increasing evidence suggests that the links between the generation of new knowledge, and its adoption and application, is spatially sensitive, ie. despite numerous reports to the contrary, *distance does matter*.

This trend raises issues of critical importance for public officials responsible for the funding and administration of PSE research in Canada. Central to that responsibility are the tasks of determining what are optimal, or even adequate, levels of funding for PSE research in Canada; evaluating the quality and effectiveness of the research conducted in PSE institutions and determining the potential and actual flows of knowledge from PSE institutions to other components of the ‘innovation system’ where that knowledge can be deployed in creating new products and processes with commercial potential, or improving existing products and processes.

The challenge is compounded by two critical factors. First, responsibility for both the funding and administration of PSE research in Canada is divided between the two senior levels of government in ways that lead to overlaps, duplication and spillovers in the administration of policy for this sector (Wolfe, 1998). This makes the task of judging the adequacy and effectiveness of current levels of funding all the more difficult. The problem of judging adequacy is also compounded by the difficulty of measuring current levels of research funding in PSE institutions. Some parts of the funding flow are measured directly, such as that from the federal granting councils, federal and provincial centres of excellence, or industry-supported research. However, other aspects of the funding, such as the proportion of the universities' own funding devoted to research, are based on statistical estimates that are widely recognized as needing further development. The first challenge in any effort to improve the measurement of both the adequacy and effectiveness of PSE research funding must be to develop more satisfactory measures of the actual levels of funding for research activity in PSE institutions.

The second challenge in developing a framework that can be used to evaluate the quality and effectiveness of PSE research lies in the difficulty associated with measuring knowledge flows. In the rush to participate in the emerging knowledge-based economy, care must be taken to distinguish between the distinct categories of data, information and knowledge. While the PSE research activity plays an important role in generating all three categories, they are not equally relevant to an evaluation of the contribution made by research to the 'innovation system'. A further distinction must be made between different categories of knowledge, particularly between the tacit and codified dimensions of knowledge. While PSE research activity is usually associated with the expansion of codified sources of knowledge, a growing body of literature on both the research enterprise, the innovation process and the nature of the university-industry linkage emphasizes the critical contribution made by the development and sharing of tacit sources of knowledge among relevant networks of actors in the innovation system. Any attempt to measure and evaluate the effectiveness of PSE research must start with a recognition of these different dimensions of knowledge flows within the innovation system.

The draft framework for quality and accountability of PSE research raises a number of critical questions. Among these are the issues of determining the right amount of PSE research to be funded; whether there is an appropriate mix of types and fields research being funded; whether the provinces are receiving good value in terms of quality and productivity from the investment in PSE research. Closely related to this is the issue that this paper sets out to address — the ways to measure and evaluate the quality, productivity and sufficiency of PSE research. The key issues concern the challenge in developing a balanced mix of measures to evaluate the effectiveness and contribution of research conducted in post-secondary educational institutions, including both universities and colleges, for those jurisdictions where there is a mandated research function. The second question concerns the relationship between the PSE research sector and the innovation system as a whole. The growing emphasis on partnerships and networking in the conduct of research activity raises questions about the type of linkages that exist between PSE research institutions and other components of the innovation system and how the knowledge generated in the PSE sector is transmitted and applied by these other components.

2.0 Knowledge Flows within the Innovation System

Innovation and technical progress are generated by a complex set of relationships among institutions which produce, distribute and apply various kinds of knowledge. The innovative performance of individual countries or provinces is influenced by the way elements of this institutional system interact with each other in the creation and application of knowledge. The central role of institutional structures in the way national economies innovate has led to the growing emphasis on national systems of innovation. A useful definition is, "A national system of innovation is that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies" (Metcalfe, 1995).

The role of the public sector in stimulating and sustaining innovative behaviour is crucial. The public sector maintains a vast array of infrastructural supports critical for the innovation process in the form of the post-secondary educational system, public R&D facilities and a wide range of institutions that support the process of technology transfer. These essential elements of the technology infrastructure

comprise what the OECD terms the *science system* in the knowledge-based economy. The science system, which includes public research laboratories and institutions of higher education, takes on a greater significance as the transition to a KBE gains momentum. The science system contributes to the key functions of:

- i) knowledge production — developing and providing new knowledge;
- ii) knowledge transmission — educating and developing human resources;
- iii) knowledge transfer — disseminating knowledge and providing inputs to problem-solving.

The OECD notes that the task of performing these functions has been made more challenging for the science system by the recent changes that it has undergone. Most science systems have been confronted with the dual challenge of managing in a period of severe budget constraint, while simultaneously coping with the rising marginal costs of scientific progress in key disciplines. It has also had to manage the transition from its more traditional role to the newer one as an integral part of the broader innovation system (OECD, 1996).

2.1 Knowledge Production in the Science System

The science system is traditionally regarded as the primary source of new knowledge, largely through the conduct of basic research at PSE institutions and government laboratories. This has conventionally been distinguished from the knowledge generated by more applied or commercial forms of research located closer to the market end of the spectrum. However, there is growing recognition that in the KBE, the distinction between these two categories is breaking down and the role of the PSE research sector is undergoing significant changes. A better understanding of the changing nature of this relationship is essential for a successful effort to measure and evaluate the quality and effectiveness of PSE research.

According to a recent exploration of these two categories, basic research seeks to widen the understanding of the phenomena of a scientific field. Its defining quality is the contribution it makes to the general body of knowledge within an area of science. This follows the OECD definition of basic research as experimental or theoretical work undertaken primarily to acquire new knowledge of the

underlying foundation of phenomena and observable facts. In contrast, applied research is directed towards some individual or group or societal need or use (Stokes, 1997). A recent working paper by the National Science Board in the US (NSB-97-186) defines basic research as “the search for new knowledge and concepts that unify or extend that knowledge. The work, stimulated by theoretical or practical questions, is conducted in the context of existing knowledge and paradigms. . . . Typically, research is designed to answer specific questions to fill gaps within the existing body of knowledge or to test the paradigm itself. Work which is intended to confirm or refine an existing paradigm may, in fact, contradict it thus opening the way for a scientific revolution.” Development, in contrast, is defined as “the process by which a new product or process is brought into being or improved based largely on existing knowledge and theory.”

In its second annual report, the National Science Foundation in 1952 defined the relationship between the two as a linear model involving the progression through a technological sequence leading eventually to product development, the final stage involving the systematic adoption of research findings into useful materials, devices, systems, methods and processes. The entire sequence was referred to as the process of technology transfer (Stokes, 1997). The linear model has been subject to considerable criticism and refinement since the early 1950s. An alternative perspective suggests that positing an absolute dichotomy between basic and applied research misapprehends the fundamental aspects of scientific research. Donald Stokes argues that research needs to be conceived as consisting of more than a one dimensional plane. The first dimension classifies research by the degree to which it seeks to expand the frontiers of fundamental understanding; the second classifies it according to the degree to which it is inspired by considerations of use. The relationship between basic and applied research moves along parallel trajectories that interact with each other, but maintain their autonomy. Science often proceeds to a higher level of understanding with little regard to the implications for technological improvement, while much technological innovation involves narrowly targeted engineering or design changes, based on existing or well understood science. “But each of these trajectories is at times strongly influenced by the other, and this influence can move in either direction, with use-inspired basic research often cast in the linking role” (1997: 87). Lewis Branscomb argues in similar fashion that much of what is classified as applied research in official statistics is really need-driven, creative research into new kinds of materials, new processes or ways of exploring or measuring and new ways

of doing and making things. He calls this *basic technological research* that involves work that creates new capabilities, as well as new understanding that goes beyond narrow problem-solving or product development (1998).

2.2 Knowledge Transmission in the Science System

The science system plays a crucial role in knowledge transmission within the KBE, primarily through the education and training of scientists and engineers. In this regard, what is essential for the effective transmission of knowledge is not only formal education in various scientific and engineering disciplines, but also effective training in the techniques and practice of advanced research. In addition, the growing recognition of the systemic character of the innovation process also leads to the understanding that a wide range of other disciplines and professions are relevant to the transmission of knowledge. The increasing role of new multimedia industries in the KBE underlines the innovative potential of creative content in the success of these industries and the importance of advanced training in the numerous fields of literature, drama, the humanities, music, design, graphic arts, etc. This makes it all the more difficult to determine the “best” distribution of research funding across existing disciplines — new fields of economic activity may draw upon research and knowledge in old lines of intellectual inquiry in ways that are completely unanticipated.

The adequacy of funding for advanced research endeavours is closely linked to the effectiveness of the PSE research sector in the performance of its knowledge transmission function within the innovation system. This has been tied in recent years to a growing range of critical issues, such as the presence or absence of critical skills shortages and the existence of an effective brain drain from Canada to other advanced industrial countries. Echoing concerns raised by the Information Technology Association of Canada, Industry Canada indicated in a document released in November, 1997 that Canada may face critical skill shortages in the order of 20,000 software engineers by the year 2000. This mirrors the position of the Information Technology Association of America. In a similar report issued last year, it argued that there were currently 190,000 unfilled positions for information technology workers at large and mid-size US companies. It further maintained that the number of bachelor degrees awarded annually by US universities in computer science fell by 43 per cent between 1986 and 1994.

There is considerable debate about the accuracy of these numbers and possible explanations for the phenomenon. One which reflects on both undergraduate and graduate training in critical areas of science and technology is the growing trend for students, especially at the graduate level to be hired before they complete their degrees. While this may speed the flow of skilled workers into the labour force, it may also reduce the supply of graduate educators and researchers available to train the next generation of students. While these shortages are usually attributed to the adequacy of general funding for PSE, they are also affected by the extent and quality of research funding. The availability of research funding attracts and holds graduate students in a particular field and may even be critical in determining whether they remain in this country or leave. Conversely, declining enrollments and/or numbers of graduate in critical fields, plus the departure of students to other jurisdictions may be important indicators of an inadequate level of research funding in these fields. However, concerns about critical skill shortages and the potential loss of key researchers underline a central fact about PSE research — it is individuals who conduct the research, not institutions. Efforts to judge the effectiveness of research outputs must recognize the importance of attracting and retaining top quality researchers to the research-intensive institutions.

2.3 Knowledge Transfer in the Science System

Finally, the science system plays a critical role in transferring and disseminating knowledge throughout the economy to other parts of the innovation system. This involves the development of growing linkages between the science system and the private sector to foster the more effective diffusion of relevant forms of knowledge. The increased emphasis by government on industrial partnering means that many recent funding initiatives by the federal government, the national granting councils, and provincial governments target research at the more use-inspired and applied end of the spectrum. The shift in this direction has been motivated by the belief that this will lead to the conduct of more industrially relevant research within PSE institutions and accelerate the transfer of applicable knowledge to private sector innovators where it can be deployed more readily in innovative products or processes. However, the extent to which this has actually occurred is extremely difficult to ascertain. Furthermore, the progressive shift in university research activity away from more curiosity-driven concerns has raised fears that the underlying base of fundamental research to drive the next generation of technological innovations may be drying up and prove inadequate to the challenge.

In general, there is a growing sense in both the US and Canada that the emphasis on targeted funding for applied research at the PSE level, coupled with the decline in the basic research role of some of the key corporate laboratories is jeopardizing the long-term status of basic research. In one of the last reports issued before its untimely demise, the US Office of Technology Assessment warned that, in light of the pressure to reduce federal budget deficits, funding for basic research at universities and federal laboratories could drop further, a change which “could potentially reduce the amount of basic research available to US firms”. A recent White Paper on Basic Research published by R&D Magazine in the US echoed this warning. It noted the growing concern among both R&D managers in industry and research administrators in universities that the shift away from basic research and a more long-term focus towards more commercially-relevant research with a shorter time horizon is drying up the pool of scientific knowledge that can feed future innovations.

As the OECD notes, “In part because of its increased importance in the knowledge-based economy, the science system finds itself torn between more traditional areas of research and investigations that promise more immediate returns. Many argue that if scientists are to create the knowledge that will generate the new technologies of the next century, . . . there should be sufficient scope to allow scientists to set research directions guided by their own curiosity, even though these do not appear to be of immediate value to industry” (1996). Judging the correct mix of basic, use-inspired basic, or applied research remains a critical challenge for those charged with responsibility for managing the PSE research enterprise. Attempts to measure the quality and effectiveness of the PSE research effort must also come to grips with the need to reach judgements about the appropriate mix. Yet the uncertainty with which the innovation process is characterized makes these judgements difficult to reach.

2.4 Dimensions of Knowledge in the Science System

As noted at the outset, the increased emphasis on the emerging knowledge-based economy places a premium on our ability to distinguish knowledge flows of relevance to the innovation system from other forms of information, as well as to distinguish between different types of knowledge. Innovative

activities rely on different kinds of knowledge and information and the failure to distinguish between them can result in serious problems of mismeasurement. For instance, a unique feature of modern information technology is its ability to “automate” what were previously mechanical activities in the handling of data by converting them to electronic processes (ie. through the use of bar code scanners) and simultaneously to “informate”, by creating vast new databases of usable information derived from the data scanned by these electronic devices. Modern communications theory distinguishes between data, elementary units of communication, and information, structured or formatted data ready for transmission. However, it requires knowledge to provide the conceptual and analytical contexts to interpret and give meaning to the information thus gathered (David and Foray, 1995). To extend the analogy used above, it is structured database programs and newer data mining techniques that help firms extract valuable knowledge from these newly generated databases.

One of the key challenges faced in the emerging knowledge-based economy is that the virtual explosion of new databases and potential sources of information places a higher premium on the role of knowledge. Knowledge in this sense is often referred to as explicit or articulated knowledge and is associated with more formal routines of scientific investigation. Knowledge generated in this fashion is transmittable in formal, scientific language and it adheres to the general scientific principles and laws recognized by the formal scientific community, much of which is located in the PSE research institutions and research laboratories that comprise the science system. The findings of formalized research endeavours are recorded in scientific reports where results are shared more generally with other members of the scientific community and the resulting laws and principles are codified in textbooks and transmitted to the next generation of researchers. These laws tend to reflect the prevailing paradigms that govern scientific endeavours within a particular discipline, and thus provide guides to future directions of scientific research (Faulkner, 1995). Explicit or articulate knowledge of this type generally corresponds to the economists’ model of research. It displays many of the qualities of a pure “public” good; it is “non-rival” in the sense that it is infinitely expandible without losing its intrinsic qualities, so that it can be used by many members of the scientific community at the same time; and it is durable in the sense of not diminishing in value with increased use (David and Foray, 1995).

This form of knowledge is distinguished from “tacit” knowledge which is neither well understood, nor readily communicated. Tacit knowledge is highly personal, hard to formalize into scientific laws or principles, and therefore, more resistant to easy transmission. It is deeply rooted in action and in the specific context, both organizational and spatial in which the individual gains that knowledge. It consists partly of the technical skills acquired by individuals through the routine performance of their jobs, whether they be researchers in PSE institutions, industrial R&D scientists, or routine shop floor workers. It also is based on an important cognitive dimension that includes mental models, beliefs and perspectives which are so deeply ingrained in the individuals’ thinking that they are generally taken for granted and thus not readily articulated. In Michael Polanyi’s famous phrase, “We know more than we can tell” (1966).

Increasingly research on the innovation process within private firms and on the transfer of useful knowledge from research institutions to the private firms emphasizes the invaluable role that this tacit dimension contributes to the innovation process. Furthermore, in direct contrast with explicit or articulated knowledge, this form of knowledge is not easily shared among an international research community using modern communications technologies. Rather it is spatially delimited and depends on proximity to be fully understood and appreciated. A final feature of tacit knowledge is that its economic value is directly enhanced by the virtual explosion of more codified and explicit forms of knowledge generated in an increasingly knowledge-based economy. The easier it is to access codified forms of knowledge, the more valuable becomes the tacit forms for sustaining distinctive advantages for individual firms and geographic regions. Proximity to research-intensive PSE institutions and the ability to access their pool of tacit, as well as explicit knowledge, may well become a critical factor in evaluating the overall benefits of their research output. Needless to say, this constitutes a fundamental measurement challenge for any attempt to assess the quality and effectiveness of PSE research. If the potentially most valuable dimension of knowledge cannot even be fully articulated, it will no doubt be difficult to measure!

3.0 The Adequacy of Existing Statistical Indicators

Efforts to measure the quality and effectiveness of research activity in PSE institutions must start with the existing basis of statistical indicators available for the task. In its recently issued Framework for a Statistical Information System, Statistics Canada employs the framework of the science system described above, but points out that we cannot adequately answer important questions about the nature of knowledge flows in the Canadian innovation system with the existing basis of statistical information, “. . . the S&T indicators which have been developed are piecemeal and at times misleading.”

The first two dimensions of knowledge flows, knowledge production and knowledge transmission, are easier to grapple with than the third, recognizing the fact that available data deals primarily with the explicit or codified dimension of knowledge, rather than the tacit. Furthermore, in determining which measures to use in charting the dimensions of knowledge flows within the PSE research sector, it is important to note that research activity can be assessed in terms of both input and output measures. While input measures provide one indication of the extent of activity occurring in either the production of knowledge, or its transmission, they serve, at best, as a proxy for the real knowledge outputs of the research sector, rather than as the equivalent of those outputs.

In measuring inputs to the knowledge production process the most obvious one is the value of expenditures on R&D in the higher education sector. Statistics Canada regularly collects data on this subject and breaks them down according to a number of dimensions, including expenditures by province, as well as by funding source and the field of research activity. The difficulty with the existing data lies in the techniques used to estimate research expenditures in the higher education sector. Statistics Canada relies on a variety of estimation techniques to determine the full value of R&D expenditures in post-secondary educational institutions, as well as the distribution of those expenditures across the major fields of science, and finally, to distribute the amount of funds by the sources of funds. A key problem lies with the difficulty in estimating the value of research activity funded out of the PSE institutions' own budgets. The existing data rely on a number of techniques used to estimate the proportion of faculty time, and consequently, the proportion of institutional budgets, devoted to research activity across the various scientific fields of study. Collecting more accurate measures of the

extent of funds devoted to research activity within the PSE institutions would require a considerable effort on the part of both the institutions themselves and provincial education ministries. However, the generation of more reliable data in this regard would be highly desirable from the perspective of improving the existing national data sources on the dimensions of research activity in the higher education sector.

Other data available from Statistics Canada include estimates of research expenditures within the higher education sector by industry. These data could serve as an indicator of the extent of research partnering between PSE institutions and private business enterprises, providing one potential measure for the effectiveness of research activity. However, once again, these data are only currently available on a province by province basis rather than an institutional basis and consequently, this limits their current effectiveness to serve as a measurement tool for evaluating PSE research effectiveness. Furthermore, these would still consist of purely input measures.

Additional sources of the data on the inputs to knowledge production within the PSE sector are available from a number of other sources, including the federal granting councils, as well as a variety of provincial funding sources. These data afford a more refined breakdown of the variety of different research activities, what the funds are directed towards and the type of different programs they are expended under. They may also include some data on the extent of industrial partnering associated with a range of different programs. While these data sources undoubtedly provide more precise breakdowns of the kinds of activities and fields of study that research funds are being expended on in the PSE sector, they represent at best a partial indicator of the total amount of research activity actually being conducted within PSE institutions.

Other sources are available for estimating the output of knowledge production within the PSE sector. Those traditional sources rely upon bibliometric measures, such as the Science Citation Index. Recent work undertaken by Statistics Canada has supported the creation of a new scientific database of bibliometric measures within Canada available through the Observatoire des Sciences et Technologies at CIRST at the University of Quebec at Montreal. The bibliographic measures contained in the

observatory's database provides detailed information on a wide range of scientific disciplines within the natural and physical sciences, the health and biomedical sciences, and engineering sciences. It also contains data on the social science and humanities disciplines. The information contained in this database were derived from the widely available Science Citation Index, but required the expenditure of a considerable amount of effort to ensure their reliability for the Canadian PSE research sector.

While these measures provide one potential indication of knowledge outputs from the PSE sector, great care must be taken in relying excessively on them to estimate and evaluate research output. The reasons for this caution are varied. Bibliometric measures as reflected in the Science Citation Indices do not always capture the full range of publishing venues used by academic researchers. In particular the comprehensivity of these databases varies considerably across academic disciplines and is considerably less reliable for social science and humanities fields than it is for the natural sciences, engineering and medical fields. Furthermore, the database as it has currently been structured, is limited to providing information on a provincial basis, rather than the narrowly institutional basis that would be required for use as a measure of research output. The data contained in the Observatoire's database could be further refined for use by provincial education authorities on an institution by institution basis. However it would require the expenditure of a considerable amount of time and effort and would likely meet with considerable resistance on the part of some educational institutions, as well as some academic bodies.

In terms of measuring the outputs of knowledge transmission, the most useful indicator would appear to be the numbers of graduates from PSE institutions and the flow of graduates from PSE institutions to other sectors of the economy. In this regard, Statistics Canada has recently completed a new survey which provides detailed information about the flows of science and technology graduates into the labour market. It does not provide a detailed breakdown of science and technology graduates by individual research institutions, but it does serve as a useful indicator of the relevance of different sources of PSE education to different industries within the national economy.

Finally, we come to the third dimension of knowledge flows, namely that of knowledge transfers. This is the most difficult dimension to obtain reasonable measures of, for a variety of reasons. Among the

most significant of the reasons are the difficulty in determining exactly what portion of the outputs of research activity are transferred to the private business sector and in what form they are adopted and used by private firms in the innovation process. Furthermore, there would be great difficulty in obtaining reliable estimates about the exact nature and measures of research outputs from individual research institutions. Finally, as the preceding discussion indicated, there are important distinctions between the explicit and tacit dimensions of knowledge flows. A growing body of academic research suggests that while the tacit dimension is considerably more difficult to estimate and measure it may, nonetheless, prove to be the more valuable.

A further complication arises from the fact that only a small portion of the research conducted within universities has immediately commercializable potential. Consequently, it is important to understand the factors that affect the ability of universities to commercialize the intellectual property developed through their research activities. A report commissioned by Industry Canada from the Canadian Institute for Advanced Research suggests that the process of commercialization is limited to two sets of actions: the identification of possible elements of valuable knowledge and their protection; and the transfer of the protected knowledge to sources that can successfully commercialize it. The successful completion of these two elements depends in large part on the assessment of whether a particular piece of intellectual property is commercializable. The costs of market assessment are quite high and finding a successful recipient for the results of specific research is critical. In general, technology push is less effective than market pull in transferring research results from the university to the marketplace. This accords with the findings of many other studies of the innovation process (CIAR, 1996).

Despite these qualifications, it remains true that there are a number of devices available to help estimate the nature and degree of these kinds of knowledge flows. One such measure is the recent survey conducted by Statistics Canada of the commercialization of intellectual property within PSE institutions. The commercialization of IP represents at best an extremely small portion of the total output of research activity within the PSE sector, and the still considerably small proportion of the total knowledge transferred from the PSE research institutions to private industry. Care should be taken in the use of this data source as a measure for estimating the effectiveness of knowledge transfer from the PSE sector to private business enterprises. A further problem that will be encountered in attempting to

use these measures is the fact that they have only been gathered on a national basis and the identity of individual research institutions is not discernible within the existing state of the data that have been collected. This was done partly to allay concerns by the individual research institutions concerning the potential uses of this data.

While some of this new data will contribute to a better understanding of the extent of technology transfer from the PSE sector to private business enterprise, they still capture at best a small proportion of the total activity. Firms' choices in adopting research advances in the university still remain more the subject of speculation, than actual study. Some recent efforts offer insights on the subject. The Yale survey queried 650 R&D managers in US firms, representing 130 lines of business. The goal was to understand interindustry differences in sources of technological opportunity. It distinguished between two roles that science plays in supporting innovation: one as an expanding pool of theory and problem-solving techniques deployed in industrial R&D, but not necessarily new science; the other as a direct source of new technological possibilities pointing the way towards new solutions to old problems. The primary finding was that the role of science as a broad pool of knowledge is more relevant than the direct research findings of scientific research. Current research is generally reported as less directly relevant to the innovative activities of industry. Industrial R&D managers value the scientific background and training of their R&D staff more highly than the current research activities of university-based researchers (Klevorick et al., 1995).

Similarly, the PACE survey conducted for DG XIII of the European Commission involved a survey of R&D managers from the 500 largest manufacturing and industrial firms within the EU. While the focus of the survey was on the full range of information sources used by these firms in the innovation process, it also provided some insights into the role of public research facilities. The survey found that the extent of reliance on public research facilities as knowledge sources varied considerably between high and low technology industries, as well as from country to country (Arundel et al., 1995). Other results from a survey of US high-technology industries between 1975 and 1985 by Mansfield reports that university-based research plays a more direct role in the processes of knowledge development and transmission, accounting directly for 10 per cent of new products and processes (Mansfield and Lee 1996).

This type of study has never been replicated in Canada. An earlier attempt to reproduce the Yale survey was unsuccessful in obtaining the required funding. These studies do not provide direct information about the quality and effectiveness of individual research institutions, but they do provide valuable insights into the nature of knowledge flows from academia to industry on an national or regional basis. As such, they can serve as one indicator available for judging the use that industry makes of knowledge produced within the science system.

An slightly different approach deployed in a study of industry–academic research linkages offers a novel insight into the nature of the relationship. This study approached the relationship from the perspective of the innovating organization, focusing on its knowledge requirements and trying to develop a better understanding of the knowledge flows from academia to industry. The study relied on interviews, but to ensure reasonable depth, interviews were conducted with a number of individuals in each company and with several companies in each sector. One of the principal findings of the study was the relative importance of informal contacts and tacit knowledge flows in facilitating the transfer of technology between academic and industrial researchers. However, it also concluded that research in public sector institutions is relatively less important than that from internal corporate sources or other companies (Faulkner, 1995).

A second aspect of knowledge flows situates the university–industry relationship in the context of the regional innovation system. The geography of production in the new economy is marked by a ‘paradoxical consequence of globalization’ — the role of knowledge and creativity places a premium on the kind of localized, or regionally–based, innovation that is fostered by proximity. Innovative capabilities are frequently sustained through regional communities that share a common knowledge base and interact through common institutions. The science system forms a central part of this environment. Proximity to the source of the research is critical in influencing the success with which new product innovations are transferred from the laboratory to commercial exploitation, or process innovations are adopted and diffused across developers and users. One prominent line of research investigated the geographic spillovers from government funding to other types of activities, such as industrial R&D.

A seminal study by Jaffe attempted to measure geographical spillovers in the US. Using patents as a proxy for innovative output, he related the incidence of patents assigned to various corporations in different states with industrial R&D and university research. His results demonstrate that there are spillovers from university research and industrial patenting. There is also an association between industrial R&D and university research at the state level. University research encourages industrial R&D, but not *vice-versa* (Jaffe, 1989). In a similar study, Acs et al. found that spillovers between university research and innovation was greater than Jaffe described (Acs et al., 1992). Using the same data as Acs, Feldman and Florida's model showed that geography matters in the process of innovation, "In the modern economy, locational advantage in the capacity to innovate is ever more dependent on the agglomerations of specialized skills, knowledge, institutions, and resources that make up the underlying technological infrastructure (of a place)" (1994: 12). This strand of research is also confirmed in the work of Edwin Mansfield, referred to above. In a survey of 70 major US companies, Mansfield and Lee found that distance helps to determine which firms reap the economic benefits from an innovation based on academic research. Firms located in the nation and area where academic research occurs are significantly more likely than distant firms to be among the first to apply the findings of the research. Firms located close to major centres of academic research are deemed to have a 'major advantage' over those located at a distance from the academic source of research (Mansfield and Lee, 1996).

The results cited above provide a better overview of the relationship between university-based research and regional innovation, but still suffer from a number of limitations. The research tends to focus on the question of the importance of different sources of technical knowledge to industry, rather than the process of technical collaboration and as a consequence, provides little insight into the means by which knowledge is transferred from the university to industry. The results of the Yale survey do not fully accord with the studies of geographic spillovers. Furthermore, because these studies were largely conducted from an industry perspective, rather than that of the PSE sector, they do not shed much light on the contribution of individual research institutions. Nonetheless, replication of these studies in Canada could provide one useful indicator of the sources and kinds of knowledge valued by Canadian firms and the most effective means of transferring that knowledge between sectors. Replication of the

more qualitative approach developed by Faulkner and Senker would also should some light on the more difficult task of tracking the tacit knowledge flows between the PSE sector and industry.

The preceding discussion highlights the complexity of the issues involved in using existing measures or developing new ones to evaluate the quality and effectiveness of the research effort at Canada's PSE institutions. It describes the three functions of the science system relevant to the innovation process and reviews the existing state of available data sources that could be used to measure research effectiveness along these lines. It also explores some lines of recent academic research that indicate additional types of measures that might be used. We should be careful not to reduce complex knowledge flows in the innovation system to existing sources of data, purely for the purpose of obtaining measures. We should work to develop new measures that more accurately captures the contribution of the research system.

4.0 References

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