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Skills required for innovation: A review of the literature

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Abstract

This review of the innovation literature seeks to identify the role of skilled labor in the process of innovation and technological change. After an introduction of main innovation theories, the role of skills is analyzed from several perspectives: (1) Independent innovator – entrepreneur; skills deployed and needed; the role of education (2)Firm –the contribution of skilled labor to innovation from within the firm and from external sources. (3) Regional systems of innovation **-** Endowment of regions and cities in human resources, regional/local labour markets and knowledge spillovers (4) National systems of Innovation**-** national institutions and policies regarding human resources, labour markets, education system and various aspects of economic and technological infrastructure. (5) Technological milieu**. -** skilled labor involved in innovation evolves in various environments such as scientific, technical and trade associations, formal and informal contacts. (6) Scientific base**.-** The role of industry-university and public-private research collaboration in innovation. (7) Is innovation skill-biased?.

The second part of the study looks at findings of recent studies of innovation and technology adoption in Canadian manufacturing and services with regard to skilled labor. Also addressed is the impact of innovation on skills. The shortage of skilled labor is widely recognised as an obstacle to innovation and adoption new technologies, especially by firms that introduce the most original innovations and the most advanced technologies.

Overall, the innovation literature offers little in terms of concrete general information on particular skills needed for successful innovation. The paper concludes with a critical assessment of shortcomings of innovation and related surveys with regard to information on skilled labor and its role in innovation and technology adoption.

Résumé

Cet examen des études sur l'innovation a pour but de déterminer le rôle de la main-d'œuvre qualifiée dans le processus de l'innovation et du progrès technologique. On y donne un aperçu des principales théories de l'innovation, et on y analyse le rôle de la main-d'oeuvre qualifiée à partir de plusieurs perspectives :

1) l'innovateur indépendant – l'entrepreneur; les compétences déployées et requises; le rôle de la scolarité;

2) l'entreprise – la contribution de la main-d'œuvre qualifiée à l'innovation provenant de l'entreprise et de sources externes;

3) les systèmes régionaux d'information – la dotation des régions et des villes en ressources humaines, les marchés du travail régionaux et locaux et les retombées du savoir

4) les systèmes nationaux d'innovation – les institutions nationales et les politiques relatives aux ressources humaines, aux marchés du travail, au système d'éducation et à divers aspects de l'infrastructure économique et technologique;

5) le milieu technologique – la main-d'oeuvre qualifiée participant à l'innovation évolue dans divers environnements, par exemple les associations scientifiques, techniques et rofessionnelles, et les relations officielles et non officielles;

6) la base scientifique – le rôle de la collaboration des secteurs industriel et universitaire et des services public et privé dans l'innovation; 7) y a-t-il un préjugé favorable pour la main-d'oeuvre qualifiée dans le cas de l'innovation?

Key-words : Innovation; skills; national innovation systems; labour market; education of innovation; effect of innovation on skills;

JEL categories: O31; J24; J44; L6; L8

Contents

Executive Summary

The innovation activity is first of all a learning process. It is closely related to skills and competencies available and effectively mobilized within the firm. However, innovators also rely on and use skills and competencies from the outside environment of the firm. These external sources of ideas, technologies as well as markets for innovation inputs and outputs are located in geographical & political as well as in technological & scientific space. After an introduction of main innovation theories or models, the role of skills in the innovation process and technological change is analyzed from several different perspectives:

1. **Independent innovator** – entrepreneur; skills deployed and needed-their sources. Whereas specialized education for management, R&D, marketing and other corporate functions is an important input to innovation, it may be a hindrance to original radical innovations contributed by independent innovators.
2. **Firm** –Its human resources, competencies, management and strategies. Its capabilities to generate innovative ideas and learn from their market partners, competitors and various institutions of technological and scientific infrastructure.
3. **Regional systems of innovation** Firms are part of and are interacting with regional-local environment, through market transactions, formal and informal interactions with other private and public institutions => regional/local systems of innovation. Endowment of regions and cities in human resources, regional/local labour markets and education system and policies.
4. **National systems of Innovation.** Regions are part of national territories and subject to, as well as constituent parts of, national political and economic systems. Some aspects of the innovation process are shaped by the national institutions and policies regarding human resources, labour markets, education system and various aspects of economic and technological infrastructure. National policies also mediate the economic, scientific and technological, cultural and educational contacts with abroad, all of which may have an impact on availability of and skills of human resources involved in innovation.
5. **Technological milieu.** In addition to being embedded in the geographic space and their respective social and political aspects described above, human resources and their skills involved in innovation also evolve in various 'technological' environments that often share what could be called 'technical communities'. This includes common educational experience and the type of work, formal and informal contacts with colleagues from the same profession but working in other firms, same or other cities, regions and countries.
6. **Scientific base.** For some purposes, for instance the role of industry-university collabouration in innovation, a meaningful analysis has to take into consideration the scientific base, its state and dynamism and the various roles universities and public laboratories play in the process of innovation in science based firms.

Inevitably, this six-category classification scheme is imperfect and rarely applicable in its entirety. But, it provides a conceptual scheme of reference helpful to organize the ideas pursued in the literature.

What can be concluded at the end of our quest for a magic recipe for a combination of skills needed for successful innovation?

First, the innovation literature does offer very little in terms of concrete general information on innovation skills. There are several reasons for this lack of information:

- The concept of innovation used in today's empirical research is too large. It ranges from revolutionary world-first breakthroughs to minor improvements of an existing product or process by the last imitator. Even though both radical and incremental innovations matter for economic growth, they are representative of very different situations and demand very different mix of skills.
- Introduction of a standard survey of innovation based on the Oslo Manual has increased international comparability of some aspects of innovation, such as their sources and effects. However, based on a large "fit all" definition of innovation, the survey questionnaire is too blunt a tool to answer more pointed questions such as those relative to the mix of occupations and qualifications used in the innovation process.
- Many countries, including Canada, adopted plans and programs to enhance national innovation activities and capacities. As the concept of national innovation system (NSI) shows, there are some common characteristics found in all NSI. However, international differences, sometimes subtle but very important, appear to be even more significant, especially as regards the relationship between the labour market demand for skilled personnel and its supply by the education system.
- Access to and capability of using various forms of agglomeration and knowledge spillovers, be it at the urban, regional or national level, play an important but largely insufficiently explored role. The relationship to the skills involved in this process is a promising field for further research.
- There is no doubt that there is an increasing need for refined information on specifics of skills, occupation and educational attainment involved in the innovation process. Introduction of long term joint work-place & employees surveys by Statistics Canada appears as a promising response to this need. It can be expected that demand for benchmarking will also eventually lead to inclusion of questions regarding the skill and qualification mix in the innovation surveys. However, one has to be suspicious of their utility if used out of national and industry context. This may be particularly true in the case of innovation in services, given their heterogeneity and close relationship with human capital.

- As technological opportunity becomes ever more tied to scientific progress, R&D is likely to become even more routine activity than in the past. The demand for engineers and scientists is growing and will continue to do so. The mix of the two forms of human capital is likely to reflect, to a certain degree at least, the ‘division of labour’ between research in the private and public sector corresponding to the NSI and overall technological progress.
- However, introduction of new products and processes on the market requires different skills and talents than painstaking experimenting so typical of many R&D activities. As the information on sources of innovation shows, marketing, sales and production staff intervene in the innovation process. The functional sources of innovation vary among users, manufacturers and suppliers according to the technical field and nature of innovation. The successful innovating firms are those that combine a broad range of competencies under an inspired and knowledgeable management.

1. Introduction

The innovation process by which private firms bring to the market new and improved products and processes, is first of all a learning process. As such, it is closely related to skills and competencies available and effectively mobilized within the firm. However, as made abundantly clear by surveys, rare are innovations that do not also mobilize skills and competencies from the outside environment of the firm. Some of them belonging to market partners, others to various institutions of technological infrastructure. These external sources of ideas, technologies as well as markets for innovation inputs and outputs are located in geographical & political as well as in technological & scientific space. The role of skills in the innovation process and technological change of which innovation is an essential component thus can be analyzed from several different perspectives:

1. **Individual innovator** – entrepreneur; skills deployed and needed-their sources.
2. **Firm** –Its human resources, its competencies , management and strategies
3. **Regional systems of innovation** Firms are part of and are interacting with regional-local environment, through market transactions, formal and informal interactions with other private and public institutions => regional/local systems of innovation. Endowment of regions and cities in human resources, regional/local labour markets and education system and policies.
4. **National systems of Innovation.** Regions are part of national territories and subject to, as well as constituent parts of, national political and economic systems. Some aspects of the innovation process are shaped by the national institutions and policies regarding human resources, labour markets, education and various aspects of economic and technological infrastructure. National policies also mediate the economic, scientific & technological, cultural and educational contacts with abroad, all of which may have an impact on the availability of and skills of human resources involved in innovation.

5. **Technological milieu.** In addition to being embedded in the geographic space and their respective social and political aspects described above, human resources and their skills involved in innovation also evolve in various 'technological' environments that often share what could be called 'technical communities'.[1] This includes common educational experience and the type of work, formal and informal contacts with colleagues from the same profession but working in other firms, same or other cities, regions and countries.

[1] The more general concept of communities in practice Brown and Duguid (1991) is not defined along technological or scientific lines but can, be in my view, be applied to these dimensions.

6. **Scientific base.** For some purposes, for instance in a study of the role of industry-university collaboration in innovation, a meaningful analysis has to take into consideration the scientific base, its state and dynamism and the various roles universities and public laboratories play in the process of innovation in science based firms.

Inevitably, this six-category classification scheme is imperfect and rarely applicable in its entirety. But, it provides one possible conceptual scheme of reference helpful to organize the ideas pursued in the literature.

2. Theories of innovation

The first historical accounts of the path breaking technological innovations of the past focused on contributions of individuals who opened new industries, new markets and new technologies. This lead Schumpeter(1939,1962) to explicitly formulate his theory of innovation as an isolated act of individual entrepreneur-innovator who is the person who discovers new, commercially untried ideas and introduces them on the market.[2] His focus was explicitly limited to major innovations creating new firms, industries and markets.

In contrast to Schumpeter's era when individuals were the dominant source of discoveries, inventions and innovations, the post World War II era, saw the arrival of the institutionalized research and development activity in large corporations and, increasingly, also in medium size and small firms. Thus after WWII, the generally accepted model of innovation became what is now called the "linear model" In this model, as described by Kline and Rosenberg (1986), "one does research, research then leads to development, development to production and production to marketing".

The linear model neglects many crucial contributions to innovation coming from other sources than R&D. It also does not account for the many important feedbacks involved in a typical innovation process. The linear model has been replaced by the "chain-linked model" (Kline and Rosenberg, 1986, 289).The chain-linked model articulates in a more realistic way the various contributions of science and other sources of existing knowledge at various stages of the innovation process. It also underlines the uncertainty involved in innovation and the contribution of other than scientific and technical competencies to a successful innovation. The Chain-linked model makes it clear that both major innovations and incremental innovations are important for technological progress. Some organizations are very effective in high risk path breaking major innovations, others in the small cumulative, evolutionary changes that reduce the increasing cost of major innovations and

[2] Schumpeter's focus on major innovation is still popular with today's historians of technology. See for instance (Mokyr, 1990, ch.11) discussion of macroinventions (i.e. major innovations) versus microinventions in evolutionary terms.

adapt them to market needs. The model also stresses the important contribution to innovation from external sources of market information, technical expertise and information.

Case studies, and more recently innovations surveys, show that innovative ideas, suggestions and inspirations originate not only from within the innovating firm. Market partners: clients, suppliers, competitors, related firms and consultants are often at the origin of an innovation idea. To reduce the risk involved in innovation, to access complementary expertise and share the costs, innovating firms increasingly collaborate with other firms, sometimes even with their competitors, with universities and public and cooperative research institutions. Precious information is also obtained from services and institutions of technology infrastructure such as publications, trade fairs and conferences, patent and regulatory information to name only the most important sources.

While some of these sources supply technical information, others provide market signals that identify potential demand –or lack of it.

As for the implications for the skills involved in the innovation process, the complex interactive web of multivariate sources of innovation suggests that it could be futile to focus the attention on the human resources in the innovating firms alone. A detailed analysis of innovations introduced in a series of modern industries suggests that innovations are not necessarily introduced by the manufacturers of the new product or the new equipment. In fact, sources of innovation vary and in some industries new artefacts are introduced by their prospective users rather than by manufacturers.

However, the functional sources of innovation are not distributed randomly. According to Von Hippel (1988) the functional source of an innovation is to a certain degree predictable and determined by its nature (product, process combination of product and process) and the functional group (manufacturers, users, suppliers and others) most likely to benefit most from the innovation. Thus the functional source of innovation is conform to economist's view that the costly and uncertain process of innovation will be undertaken as a profit maximizing response to market and technological opportunity. To the extent that the functional source of innovation can be observed and predicted, it provides some information on the skills likely to be involved in the innovative process. To identify the functional source of innovation and their implications for the skills involved in the process requires a more refined approach than a statistical analysis of sources of innovations available from innovation surveys. An understanding of the economic and technical relationships provide a deeper insight in the innovation process, its sources and skills involved.[3]

[3] Examples provided by Von Hippel show that for instance major and minor innovations of scientific instruments were not introduced by their manufacturers but first by their users i.e. scientists and researchers using the instruments. Often an innovation is attributed to its

The distinction between major innovations that introduce, so to speak, a "new species", leading to the disappearance of the old ones and the gradual, continuous accumulation of incremental improvements, invites an analogy with the theory of evolution (Nelson and Winter, 1982). Like biological species, firms evolve, those that have more adaptable standard procedures – routines- to deal with competition will prosper and grow at the expense of the less successful ones (cited by Mokyr, 1990, p.275). Even though according to its critics (De Bresson C., 1987), the analogy has severe limitations, it provides useful insights in our understanding of technological change.

According to Mokyr(1990) the analogy is more between a specie and a technique than between a specie and a firm. Technological change occurs through emergence of inventions and innovations. Like mutations in the world of biology, innovations represent deviations from the standard technology. They are exposed to series of tests on the market place. The process of natural selection provided by the market place, eliminates most of them, they do not survive infancy.

The innovation process is fraught with major uncertainties.[4] The basic uncertainty and the irreversibility of technological change underlines the importance of diversity and experimentation as a means of avoiding to be locked up in sub-optimal technology.

In a recent symposium on evolutionary economics Nelson (2002) reviewed the evolutionary approach and its contribution to our understanding of evolution of technology and industry structure. The process is close to the Schumpeterian view of competition and conform to industry life cycle approach (Utterback and Abernathy, 1975).

manufacturer, even though the actual inventor and innovator was a user, supplier or an outsider.
Von Hippel's insight complements the now well recognized pattern of intra and interindustry flows of new technology identified by patent and innovation statistics in studies attempting to measure R&D spillovers and their effect on social versus private returns to innovation and R&D.

[4] Even though it is to a limited degree possible to predict, at short and medium term at least, evolution of sciences and technologies, it is much more difficult predicting how technologies can be transformed into working artefacts that are useful, and the appropriate organisational practices to develop, produce and sell them Utterback and Abernathy, 1975). It is therefore along these dimensions – products and organisational practices, rather than technological fields – where diversity and experimentation are likely to be the basis for competition in the contemporary innovating firm. In this context, the distinction made by Nelson (2000) between knowledge as technological understanding (strong and reliable), and knowledge as organisational practice (weak and unreliable), is particularly relevant (Pavitt, 2002).

In contrast to the neoclassical theory which is based on the hypothesis of complex decisions being solved by perfect rationality, the evolutionary theory (ET) assumes bounded rationality and stresses the importance of cumulative learning, partly by individuals, partly by organizations and partly by society (Nelson, 2002).

The evolutionary theory recognizes the importance of individual skills in the innovation process but nowhere does it seek to identify specifically the role of various individual skills and competencies in the process of innovation or technological change. Rather, the authors stress the parallel between individual skills and their cumulative development though codified and, even more important, tacit learning, learning by doing and learning by using on the one hand, and the other hand development of competencies – or what they call routines by organizations.

3. The innovator

By its nature innovation is a multidisciplinary phenomenon covering a vast field from psychological literature exploring the particularities of an "innovative" mind to studies examining innovation in the social, historical and cultural context (for a good example of the breadth of the subject see Shavinina, 2003).

The competencies required to introduce an innovation are very different from the skills employed in scientific research and in R&D activities of large firms. To find a meaningful analysis of characteristics and skills required for introduction of innovations we have to return to Schumpeter's analysis of the long term development and structural change in capitalist economies. According to Schumpeter (1939, 94) innovation is "*a change in some production function which is of first and not of the second or still higher order of magnitude*. The entrepreneur is the person who discovers new, commercially untried ideas and introduces them on the market. Introduction of those 'major' innovations entails usually construction of new plants and often creation of new industries. In the process of creating new products, processes and markets, entrepreneurs and their innovations may destroy the existing products and replace them with new ones in the process of 'creative destruction' Schumpeter (1962, 81).

Radical innovations create new industries and revitalize economic development. In his earlier writings, Schumpeter's idea of an entrepreneur- innovator was that it must be a "new man" ready to take risks involved in introduction and realization of new ideas. The innovator overcomes obstacles inherent in the process driven by expectation of large profits associated with his temporary monopoly advantage. Later, Schumpeter (1962) shifted his emphasis from future monopoly expectations to existing monopoly advantages as the essential factor in allowing the introduction of new ideas into economic life (Freeman et al., 1982, cited by Coomb, Saviotti and Walsh, 1987, 95).

Creation of spun-off high-tech companies by former employees of large enterprises who were unable or unwilling to pursue their innovative dreams in the bureaucratized structures of a large corporation illustrates Schumpeter's conception and description of 'typical' innovators. In Schumpeter's (1939) perspective an entrepreneur is an individual who carries out an innovation. An entrepreneur may, but need not, be the "inventor" of the product or process he introduces. Also, he may, but need not, be the person who provides the capital. It is leadership rather than the ownership that matters! Schumpeter recognizes that entrepreneurs come from various social classes and professional backgrounds. He does not explore the issue of the origin of inventions, nor does he venture in enumeration of specific skills needed by a successful innovator.

However, as discussed eloquently by Baumol (2005), the competencies needed by innovators are very different from the skills needed by professionals conducting research activities. He notes that breakthrough inventions are contributed disproportionately by independent inventors and entrepreneurs who often have only basic education.[5] On the other hand, the large firms focus on cumulative, incremental (and often invaluable improvements).[6] They employ researchers highly educated in extant knowledge with high academic degrees. According to Baumol (2005, p.38):

> "rigorous education plays a critical role in support of technical progress, and R&D expenditure of giant corporations together with the efforts of the independent entrepreneurs-innovators provide a crucial contribution to the process".

The corporate contribution to innovation and that of the innovating entrepreneur are characteristically different from one another and play complementary roles. Even though there are no curricula for education of innovators as such, the objectives would be quite different from those pursued by engineering and scientific education. To cite again Baumol (2005,35):

> "Education designed for technical competence and mastery of available body of analysis and education designed to stimulate originality and heterodox thinking tend to be substitutes rather than complements. Education is a help and may be a hindrance to innovation."

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[5] This assertion is contradicted by detailed case studies of major innovations that suggest that even in the nineteen century before emergence of widespread organized R&D activity, most of innovators in several major manufacturing industries had a scientific or engineering background (Bonin and Desranleau, 1987)

[6] The independent innovator and the independent entrepreneur have tended to account for most of the fundamentally novel innovations. Large business firms that account for nearly 3/4 of US expenditures on R&D, follow relatively routine, predictable goals slanted toward incremental innovations rather than revolutionary breakthroughs (Baumol,2005).

However, Bonin and Desranleau (1987) who overviewed a sample of major innovations in several industries and countries over a long period found that majority of inventors and innovators were technically or scientifically trained. In many cases it is not possible to clearly separate the role and person of inventor and innovator, which may in part explain the apparent contradiction between Baumol's and Bonin & Desranleau's findings.

4. Innovating milieu

Originality and heterodox thinking flourishes, according to Florida (2002a) in large diversified cities tolerant to immigration, alternative life styles and characterized by stimulating artistic life. This milieu attracts educated, creative people in all professions, including those working in high technology (Florida, 2002a; Florida and Gates, 2002; Gates, 2004. As a result, the US cities and regions that are becoming the leading centers of the creative class[7] have much higher economic growth than cities with a high concentration of working class occupations.

The tolerant, multicultural and creative character of a city is measured by the author's bohemian index. Florida tests the association between the geography of bohemia and the relationships between it, human capital, and high-technology industries. The underlying hypothesis is that the presence and concentration of bohemians in an area creates a stimulating milieu that attracts other types of talented or high human capital individuals. The presence of such human capital in turn attracts and generates innovative, technology-based industries. A series of statistical tests show positive and significant association between the bohemian index and concentrations of high human capital individuals and between the bohemian index and concentrations of high-technology industry (Florida, 2002b). A replication of the US study by Gertler, Florida, Gates and Vinodrai (2002) shows that the correlations between the various measures of diversity and technology are even higher in Canada than in the U.S.

According to Florida's coauthor Gates(2004), Canada and the United States have begun to diverge in social policies and attitudes such as those regarding immigration and gay rights. "In the global competition for

[7] The distinguishing characteristics of the creative class is that its members engage in wok whose function is to *"create meaningful new forms"* Florida(2002a,3). The creative class thus includes not only scientists, engineers, university professors but also poets and novelists, artists and entertainers, non-fiction writers, cultural figures, analysts and other opinion makers as well as "creative professionals" working in various knowledge-intensive activities. The creative class contributes to growth of the city or region where it is concentrated by the vary fact that its members are paid better- on average twice as much - than the working class and their spending has a multiplicator effect. More important, and closer to our subject, is the important contribution of the members of the creative class to new things, new life styles and innovation.

creative workers, Canada's approach augurs well for developing a cultural and social climate attractive to the "creative class." Observing the recent anti-elitist trend toward traditional values and less tolerant society in the US, Florida (2004) is apprehensive that it could ruin American economy.

Importance of diversified urban centers for economic development and particularly for innovation has been recognized earlier by Jacobs (1969,1985). In contrast with the now very popular concept of clusters, Jacobs underlines the importance of urbanization economies realized through the exchange of complementary knowledge across diverse firms and economic agents within urban centers. Glaeser et al. (1992) tested the hypothesis of Jacob's externalities and found that more diversity in a local economy is associated with more growth.

Audretsch and Feldman (1996) found that 96 percent of new products introduced in the US were brought to the market in metropolitan area, of which 45% in four cities New York, Los Angeles, Boston et San Francisco. They concluded that for industries sharing a common science base urbanization economies are as, or more, important than localization economies and diversity more conducive to innovation than specialization. Diversity across complementary industries sharing a common base – a crucial qualification- results in greater returns to R&D. The argument in favour of industrial diversity rather than narrow specialization is also supported by Jaffe, Trajtenberg and Henderson (1992) and Glaeser at al. (1992). The implications of these conclusions relative to skilled labour seem obvious. Availability of a pool of diversified rather than narrowly specialized skilled labour is of crucial importance to innovation. It is more easily found in large, diversified metropolitan areas than in a mono-industry urban or regional clusters. However, Desrochers (2001) finds that the operational definition of inter industry knowledge spillovers used by Jaffe, Trajtenberg and Henderson (1992) do not fit well Jacobs' idea of diversity. According to Desrochers, Jacob's theory is based on innovation inspired by cross fertilization between production of various product categories that often transcend the statistical definition of industries. Jacobs' economies of urbanization seem to be more relevant for innovation in "young" industries at the beginning of their product life cycle.

5. Regional systems of innovation - why do innovative firms agglomerate- what is the role played by skills?

The idea that regional concentration of an industry provides benefits due to concentration of "people following the same trade" goes back to Marshall:

> "When an industry has chosen a locality for itself, it is likely to stay there long; so great are advantages which people following the same trade get from near neighbourhood to one another. ….Good work is appreciated, inventions and improvements in machinery, in process and the general organization of the business have their merits promptly discussed; if one man starts a new idea it is taken up by other and

combined with suggestions of their own; and thus it becomes a source of further new ideas." (Marshall, 1949, 152-153, cited by Feldman, 1994).

Krugman (1991) elaborates on Marshall's concept of industrial districts and considers the knowledge externalities associated with spatial concentration of specialized labour pools as one of the main reasons of spatial concentration of industrial activity. Long time a quasi-exclusive domain of geographers, the spatial aspects of industrial activity and innovation have attracted attention of empirical economists studying the externalities involved in innovation activities. A great deal of this literature concerns the spatial interaction of university research and innovation (Jaffe, 1999); Jaffe, Trajtenberg and Henderson,1992; Acs et al., 1994). Feldman, (1994) and Audretsch and Feldman(1996) identify strong co-location of university research and industrial R&D at the state level resulting in generation of patents and innovations. An excellent survey of empirical work in this field of "new economics of innovation, spillovers and agglomeration" is (Feldman, 1999), followed by Audretsch-Feldman forthcoming in the Journal of Technology Transfer.

In a related but distinct field of inquiry economists are quantifying the social benefits cities receive from the presence of educated people- i.e. from the stock of human capital. Moretti (2003) reviews research in this field and estimates the effect of the stock of human capital on productivity and other forms of social benefits such as crime reduction and voting.

Even though most of studies focus on the co-location of university and industrial R&D activity, commercial introduction of new and improved products and process requires also a significant contribution of skilled personnel in complementary activities, first of all in business services. Thus the pools of skilled manpower essential for innovation activity require a combination of university and industrial researchers, complemented by specialized skills in business services (computer services, marketing, financing, patent attorneys, management consultants etc (MacPherson,1988), all integrated in a spatially concentrated network of institutions of technological infrastructure and firms in related industries (Feldman, 1994, 51).

Saxenian(1998) illustrates the functioning of 'open' labour markets in the Silicone Valley and contrasts it with the closed, hierarchical labour markets typical of the Route 128 in Massachussets area. The open labour market in Silicon Valey is characterized by high mobility of skilled individuals between firms and industries. Since many firms have been spun-off by former employees, a practice that is not only tolerated but sometimes even encouraged, there is an active exchange of information between employees and between firms who often recombine into new ventures. The easy creation of new firms, their successful development as well as their frequent failures are essential elements of learning through experimentation. Professional loyalties to technical communities form informal networks. Even though employees are loyal to their companies, they are even more loyal to their professional and social networks.

> "What distinguishes Silicon Valley is the extent to which the region's networks ensure the rapid spread of knowledge and skill within the localized industrial community." (Saxenian, 1998, 35).

The knowledge-based economy, evolves, according to Florida (1998, 25) to "learning" regions whose competitiveness is based on knowledge creation and its continuous improvement. In contrast to a Mass Production Region, based on low-skill low cost Taylorist labour force, the human infrastructure underlying a learning region is based on knowledge workers, continuous education and training and globally oriented communication infrastructure.

In some science-based industries the availability of skilled manpower and knowledge producing institutions act as attractors of innovating firms. The typical case are regional clusters of innovation in biotechnology. Knowledge producing institutions such as universities and public research institutes constitute and develop pools of skilled manpower that attracts innovative biotechnology firms and acts as incubators in biotechnology. The pattern has been observed abroad (Acs et al.1994; Yarkin, 2000, cited by Niosi (2005)) and in Canada as well (Niosi, 2005).

But in other science-based industries, skilled personnel rather than attracting innovating firms is attracted by the presence of major corporations, by the "corporate attractors". The latter are large innovative firms that act as corporate "assemblers" of subsystems and parts produced elsewhere, often in other regions or countries. The prime example is the aerospace industry with its R&D intensive but well codified technology. The knowledge in this industry flows internationally through the supply chain management. Design and production does not necessarily take place in the same locality. Foreign examples are Seattle, the seat of Boeing and Toulouse the assembler of Airbus (Longhi, 2002). The Canadian example is the specialized aircraft industry cluster in Toronto and the final assembler in Montreal, both today belonging to Bombardier.

Toronto and Montreal provide interesting contrasts with regard to different impact of major corporate attractors on the skilled manpower. Toronto aerospace industry relies to a great extent on immigration of specialised professionals and skilled manpower (Niosi, 2005, p150). In contrast, in Montreal, less open to immigration and with a less mobile manpower, the growing demand of aerospace firms for specialized skilled personnel led to creation of several collaborative initiatives with local universities. Their primary objective is training of university graduates, collaborative research and networking (Niosi, 2005, 77).

The experience of the Canadian telecommunication equipment industry and related firms in other industries is different from both biotechnology and aerospace experience discussed above. In contrast to aerospace, where the large prime contractor *attracts* most companies to the area, in the information and telecommunications technology sector the incumbent dominant firms- in the case of telecommunications Nortel Networks (formerly Northern Telecom) in Toronto and Marconi and Nortel in Montreal and Government laboratories in

Ottawa- attracted Nortel. These large firms subsequently *incubated* new firms by the spin-off movement of researchers and managers.[8] It contributed to the creation of specialized labour pools by hiring thousands of skilled workers for their own research and production and by contracting out various complementary business services. This labour pool in turn attracted development of new firms, some well established abroad, others newly created (Niosi, 2005). Thus the telecommunication clusters in Canada (initially Toronto and Montreal, more recently Ottawa) resemble more the regional innovation system based on local network externalities advanced by Audretsch-Feldman and Jaffe, Trajtenberg and Henderson than the aerospace clusters. An interesting feature is that the production activities of electronic components are increasingly located separately from the design and product innovation concentrated elsewhere, while the skilled professionals employed in design activities are located in Ottawa, Toronto and Montreal.

While Niosi (2005) focused on and found clusters in a limited number of science-based, high tech industries, the existence of Canadian clusters in other, less technologically progressive industries is still open to question.

A test of Porter's cluster hypothesis by Wagner (2005) finds no support to a hypothesis that manufacturing firms located near their rivals or universities are more innovative than other firms in the same industry are, except at extremely short distances. Thus the decision makers who put their bets and taxpayers money on development of innovative clusters in any industry and any locality would be well advised to examine the mixed evidence in support of this new panacea.

6. *National Systems of Innovation*

The theory of innovation has progressively integrated several major components or building blocs:

(1) For technological innovation to occur existing or potential markets are essential.

(2) The research and development in private firms but also in university and public laboratories provides an essential input to innovation activity.

(3) Governments have to organize and usually also finance an education system turning out qualified personnel (technicians, engineers, scientists, managers, and other professionals) taking part in the innovation process.

(4) Governments and delegated public and semi-public institutions provide the regulatory framework and participate in financing institutions of technological infrastructure. They coordinate activities of various agents and provide incentives for innovation and technological change to overcome market failures that would otherwise lead to suboptimal investment in innovation and technological change.

[8] Niosi (2005) describes how government policies, political developments in Canada and decisions of multinationals played a major role in establishment and migration of the major corporate players in the ICT field

(5) Existence of various externalities (agglomeration economies, knowledge spillovers, economies of scale external to the firm or industry, economies of scope and network economies) enhance or hinder innovation activity). They explain why innovations are not distributed evenly over the geographical and/or economic space. (Niosi, 2000).

These components are not independent. Earlier studies (Lundvall B.A.(1992); Nelson (1993), and Freeman (1987, 1995, 1997) found that innovation activities in different countries are to a significant degree influenced by the framework created by the five components enumerated above.

Since we are interested in NSI as a conceptual framework for a better understanding of the role of skilled personnel in the innovation process, it is useful to consider the NSI in a broad definition. This definition includes not only R&D institutions and public regulatory agencies (=NSI in the narrow sense)but also supporting private institutions such as the financial system, and the mixed and public ones such as education system and technological infrastructure. A reader familiar with the new theories of international trade, international production and economic geography (Krugman, 1991) will find some familiar ideas from these fields applied to NSI. For a brief presentation of the concept of NSI in the Canadian context see Niosi (2000).

More recently Lundval stressed the learning aspects of NSI. “Innovation is a learning , searching and exploring process which can be expected to eventually result in new products, new techniques, new form of organization and new markets (Lundwall, 1995; OECD, 1997 on National systems of innovation).

The emphasis of the Canadian SI on the importance of learning, the national education system and institutions with regard to human resource perspective in a learning society is developed by B. Johnson, 1992, in Lundvall(1992).

The first study of the Canadian National System of Innovation (CNSI) by McFetridge, (1993) appeared in Nelson (1993). In his study of the CNSI Niosi (2000) presents first the evolution of the Canadian R&D system from its beginnings to the nineties and, in more detail, the changes that occurred in the 1990s. More interesting for our purpose is the rest of his book devoted to presentation and analysis of his team’s survey results[9].

According to the study university researchers complain about the heavy load of teaching and advising that hinder their research activities. (Niosi, ibid, Table 3.14, p91). On the other hand, there is evidence of increased synergy, coordination and collaboration and more ‘for profit’ motivation among the three major players in the CNSI.

[9] The target population of the survey included 559 industrial, government, university and non-profit laboratories employing more than 25 R&D employees. The study is based on 148 observations.

A non-negligible part of the CNSI is constituted by activities of Canadian R&D laboratories abroad. They are mostly expatriate R&D laboratories of Canadian multinational corporations. "They are crucial knowledge acquiring assets in the international competition of firms, and they bring to Canadian MNC many valuable patented technologies" (Niosi, op.cit., p.105). In contrast, looking for foreign skills and university ideas seems a minor consideration for Canadian Companies conducting R&D abroad (Niosi, op.cit.,184).

7. Is innovation skill-biased?

The microeconomic evidence from surveys of innovation and adoption of new technology presented below in this paper suggest that firms engaged in innovation and/or adoption of advanced technologies experience severe shortages of skilled personnel. Where available (Baldwin and Hanel, 2003; Mark, 1987), information on the effect of innovations on the skills of personnel is showing unequivocally that the proportion of firms which experienced improvement of skills and/or increased employment of white color workers relative to blue color workers, is far larger than that of firms reporting the contrary effect.

For earlier studies see a historical overview by Allen (1986) and an interesting survey of earlier studies, including his own by Globerman (1986). The latter examined the literature that looked into the relationships between the level of education, the type of training received and capabilities of workers and managers to adapt to technological change. It contains a thoughtful discussion of links between technological change-related demand for skills and education. The study concluded on a rather agnostic note that the evolution of technological change does not necessarily translate into increased or decreased demand for skills, nor does it increase demand for better educated work force. The section of the paper discussing the relationship between technological change and education remains a relevant contribution to today's discussion of the appropriate response of the education system to challenges presented by the technological change.

The more recent macroeconomic evidence from OECD countries shows that at least since the end of the seventies, less-skilled workers have suffered reduced relative wages, increased unemployment and sometimes both. "The labour market outcomes of less-skilled workers have worsened in the developed world in the past two decades, despite their increasing scarcity relative to the rapidly expanding supply of skilled labour." (Berman, Bound and Machin, 1998)[10].

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[10] In the U.S. real wages of young men with twelve or fewer years of education fell by 26% between 1979 and 1993 and have not recovered since (Berman, Bound and Machin, 1998). See their article for references documenting the decline of wages, employment or unemployment in the United States and other OECD countries. However, this does not prove that all white collar workers are necessarily more skilled than the blue collar

The two main explanations of the increasing employment and wages of skilled personnel despite their growing supply include skill biased technological change (SBTC) and increased exposure to imports from low-wage developing countries.

Berman, Bound and Machin, (1998)argue that the principal cause of the deterioration of demand for less skilled workers is pervasive skill biased technological change (SBTC) that is occurring not only in the U.S. but in all developed countries and even in less developed ones. Under the assumption of such a pervasive SBTC its effect on the relative decline in employment of less-skilled (production) workers in manufacturing is about eight times that attributable to increased trade. Since technological change in services has been also characterized by increasing use of ITC technologies (Levy and Murnane,1996) and is also skill-increasing, it adds its effect to the one exercised by SBTC in manufacturing.

The shifts in relative demand of labour that favour skilled workers were also observed by Machin and Van Reenen (1998). They show that as industries move to higher R&D intensities and increased computer usage, the demand for less skilled labour declines relative to demand for skilled labour. A study by Autor, Katz and Krueger (1998) shows that demand for college graduates in the U.S. has been increasing over the past fifty years. However, the pace of within-industry skill upgrading accelerated since the seventies mainly owing to increased use of computers and related technologies. In a recent study based on firm-level data, Bresnahan, Brynjolfsson and Hitt (2002) conclude that the increased demand for high-skilled labour associated with ICT diffusion may in fact be more attributable to skill-biased organisational changes induced by ICT than to 'raw technical change' itself.

But why should technological change be biased in favour of skilled labour? Acemoglu (2002)argues that SBTC is an endogenous reaction to the increased supply of skilled personnel on the labour market. The argument goes as follows. When there are more skilled workers, the market for technologies that complement skills is larger, hence more of them will be invented and new technologies will complement skills. This is an explanation ignoring the path dependency of technological change. The path dependency may not make it possible to redirect technological change in function of the changing relative supply of skilled versus less-skilled workers on the market.

The very existence of the SBTC and its effect on wage inequality is not beyond controversy. Card and DiNardo (2002) show that in contrast to the 80s, the wage differential between skilled and unskilled workers has stabilized in the early nineties in spite of a continuing advance in computer technology. SBTC also fails to explain the evolution of other dimensions of wage inequality. Instead of crediting SBTC as the main cause of

workers they replace. The skills of the two groups are different; the new ones replacing the old ones.

the increasing wage inequality between the skilled and unskilled workers, the authors review several possible other causes of this temporary phenomenon. Primary candidate being the fall in real value of minimum wage in the early 80s, possible other culprits include the decline of unionization and relocation of labour after the 1982 recession.

Beaudry and Green (2005) also contest the SBTC hypothesis. They show that the observed pattern of evolution of wage differentials and returns to skills over the 1976-2000 period in the US can be explained by the change in the ratio of skilled labour to physical capital without resorting to the SBTC hypothesis. A part of this evolution may be due to a mismatch between demand for skills in Information and communication technologies and other domains as argued by Forth, Mason and O'Mahony, (2002). The authors show a recent breakdown of IT related occupations and their changes in the 1991-1996/ and 1996/7-2000 in England and Wales. They conclude that the mismatch between ICT skills supply and demand declined in the early 2000s.

Information and communication technologies are considered by many economists and students of technological change a primary example of a recently introduced contemporary "General Purpose Technology". As notes Lipsey et al. (2005, p.422), a new GPT typically requires a different mix of skills than the older GPT in addition to some new ones. Initially the rapid shift in the pattern of demand favours some skills and professions while it abandons others. The relative speed of demand shifts and supply responses lead to changes in relative wages and increased inequality of income distribution. Once the supply adjustments catch up with demand shifts the excess demand for certain skills and the resulting salary differences decline.
Commenting on the technological change introduced by ITC through the prism of GPT, Lipsey et al (2005,p.422) explain in fairly general terms the observed tensions in the labor market and the resulting changes in relative wages of high-skill versus low skill workers during the ITC revolution. Interesting as the concept of GPTs might be for other purposes, the authors that introduced and work with it paid little attention to specific skills involved in innovations underlying the emergence of GPT.

The literature on the employment effects of innovation, technology adoption and technological change is expanding rapidly and the brief overview above is necessarily highly selective and incomplete since the primary objective of this paper is the type of skills required for successful innovation and not the effect of innovation on skills.

After a thorough search of the economic and management literature for concrete evidence on the occupational characteristics and skills involved in creation of innovations I came out almost empty handed. Aside from case studies and histories of innovations, the only paper that dealt at least partially with the subject on a sector wide level reassured me, since the author (Pfeiffer, 1997) also deplored the lacuna in the literature regarding the role and use of human capital in the creation of innovation. The skill mix observed in West Germany[11] is an illustration of the occupations (still rather broadly defined) involved in innovation.

Table 1. Skill structure of the work force in production and R&D departments of innovative and non-innovative East and West German firms in 1994 (in % of all firms in manufacturing)

type of firm	innovative [a]		non-innovative	
region	East	West	East	West
production department				
engineers/scientists	11.6	8.0	11.6	6.9
technicians/ masters	7.4	9.3	9.1	8.2
skilled workers	58.0	41.4	58.5	43.3
others	23.0	41.3	20.8	41.6
R&D department [b]				
engineers/ scientists	58.1	35.6	[c]	
technicians/ foremen	7.7	19.2		
skilled workers	30.6	25.7		
others	3.7	19.5		

Source: MIP 1995, ZEW; 934 observations; [a] a firm is said to be innovative, if it has introduced product or process innovations in the past three years; [b] contains 157 firms in the West and 7 firms in the East German sample. [c] Non-innovative firms do not have R&D-departments.

Source of the Table: Pfeiffer (1997).

8. Innovation and skilled personnel in Canada

Sources of innovation

Innovation results from complex interactions between the impulse of science and the attraction of the market. Innovation activity depends on the firm's capability to create and acquire knowledge that not only creates inventions but also brings innovations successfully to the market place. This capability rests both on a firm's talent for internal problem solving and its ability to forge productive external linkages via networks, strategic alliances, and user-producer relationships. The process by which firms acquire and generate knowledge is at the heart of innovation activity (Baldwin and Hanel, 2003).

[11] Owing to the particular situation of the GDR before German unification, information on East Germany is likely to be less relevant.

Ideas and information for innovation come from various internal and external sources. The four main internal sources of innovation are personnel in management, R&D, sales/marketing and production. Innovation surveys (IS) provide information on the percentage of firms that identified any of these functional units as being important source of information for their innovation activity - multiple choices are allowed. According to the information from IS, the relative importance of internal sources of information and expertise depends on the nature of innovation (product-process- or both), their originality, as well as on the size of the firm, its ownership and on the industry to which the firm belongs.[12] Unfortunately, there is no information on the type and level of education and training of the personnel employed in these activities. One can only guess the type of skills and educational attainment of the personnel in each of the four categories. In spite of this shortcoming, the available information shows that staff employed in all four functional areas, whether employed in a separate administrative unit or not, contribute to the innovation process.

The most frequently cited source is management, partly at least because small firms often do not have separate administrative units for R&D, marketing and production activities and the personnel in charge of these activities belong to the management category. When all innovating firms are considered, R&D and marketing/sales are of about equally frequent sources (43-44%) of innovating ideas. The relative importance of R&D is highest in industries belonging to the science-oriented 'Core' sector and lowest in the predominantly consumer goods industries included in the 'Other' sector.[13] See industry details in Table A-1 in appendix.

The importance of R&D is increasing with the size of the firm and the originality of the innovation. It is highest for the largest firms creating original world-first innovations. This suggests that smaller firms' innovations are less R&D intensive and depend more on innovative marketing. External sources of ideas leading to innovation are a

[12] Survey of innovation and advanced technology in manufacturing (1993) is analyzed by Baldwin and Hanel (2003). The sources of innovation in manufacturing according to the more recent Survey of innovation, 1999, can be found in Landry and Amara (2003).

[13] The typology of 'core', 'secondary' and 'other' industries introduced by (Robson et al., 1988) assigns industries to the three technology sectors according to their role in generation and diffusion of innovations. See the enumeration of industries included in each technology sector in Appendix, Table A-1.

very important complement to internal sources. Ideas from market related external sources [suppliers, costumers and related firms (parent and sister companies of Canadian and foreign owned firms] were credited by 68% of innovating firms. Information spillovers from competitors, trade fairs, professional publications, public R&D laboratories and universities &colleges and the patent office were used by 46% of innovators. Another source of inspiration mentioned by about 15% of innovating firms were transactions with consultants and private R&D institutions. The use of internal and external sources of ideas depends on the nature and originality of innovation, the size of the firm and the industry. For more details see Baldwin and Hanel (2003, ch.4).

Table 2.
Internal Sources of Innovative Ideas, Manufacturing, 1993
(% of innovators using a source)

Sector	Management	R&D	Sales & marketing	Production	Other sources
All	53 (2)	44 (2)	43 (2)	36 (2)	3 (1)
World-first	43 (5)	66 (5)	40 (5)	26 (4)	6 (2)
Large (500+)	35 (4)	64 (4)	37 (4)	24 (3)	4 (2)

Source: Baldwin and Hanel(2003,Table 4.1), based on Statistics Canada Survey of Innovation and Advanced Technology,1993.
Note: Standard error in parentheses.

Owing to methodological differences, results from the more recent Survey of innovation, 1999 presented in Table 3 below, are not directly comparable to results from the earlier ISAS (1993) presented in Table 2 above. Both sets of results suggest that the relative importance of innovative ideas from the R&D, marketing and production staff is increasing with the size of the firm and the originality of innovation activity. There are, however, significant unexplained differences between the two tables, especially regarding the importance of production staff.[14]

The importance of R&D, especially for the creation of original, world-first innovations is further documented in Landry and Amara (2003) study. When the other variable are controlled for, their

[14] One possible explanation could be the fact that the earlier survey (1993) included separate questions on the origin of ideas and origin of technology used in the innovation process. The production department is often the origin of technology used in the innovation activity. The survey (1999) included only a single question on the origin of ideas for innovation. Respondents to 1999 questionnaire may have included in their response the origin of technology, which would have increased the percentage of respondents selecting ‘production’ in their response.

results of a multinomial logit regression suggest that compared to firms that did not use R&D as source of information, firms that did use this source were more than twice (2.1) as likely to introduce a world-first innovation. The effect of using marketing staff is less important, but still positive (1.42).

Table 3.
Internal sources of innovative ideas, Manufacturing, 1999
(% of innovators using a source)

Industry	Internal sources of information									
	Management		R&D		Marketing		Production		Other sources	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	76.9	A	53.4	A	66.4	A	72.5	A	14.7	A
World-first	75.6	n.a.	77.8	n.a.	77.8	n.a.	73.2	n.a.	n.a.	n.a.
Large (500+)	75.8	n.a.	68.9	n.a.	72.0	n.a.	80.3	n.a.	n.a.	n.a.

Source: Author's tabulation from Landry and Amara, 2003
Based on Statistics Canada Survey of Innovation, 1999.

In addition to information on internal and external sources of ideas for innovation, the Survey of Innovation and advanced technology, 1993 provides also information on internal and external sources of technology used to implement the innovation. The Table 4 shows that experimental development and production rather than research are the principal internal sources of technological information used in the innovation process. Note the importance of the production staff as a source of information on technology (cf. note 13 above). Information on technology sources is not available for the more recent surveys.

Table 4.
Internal Sources of Ideas for Technology Required for Innovation, Manufacturing, 1993
(% of innovators using a source)

Type of innova	Research	Experimental development	Production engineering	Standard Error
All	32	52	52	(2)
World -1st	47	60	48	(5)
Canada-1st	30	53	51	(4)
Other	26	48	54	(4)

Source: Baldwin and Hanel (2003, Table 4.10)
Note: 1) the standard errors are the mean values of the individual s.e.'s in the row.

Service industries

The large share of total economic activity accounted for by services, underlines the economic impact of innovation in this sector. Not much is known about innovation in the traditional services industries (Hanel, 2005) but the Survey of Innovation, 2003 of selected service industries reports among other data information on sources of innovative ideas. About two thirds of innovating firms got the ideas from firms' management, less (56%) from scientific research and development personnel. There are very large differences in the contribution of R&D staff to innovation. It is understandably extremely high in Scientific research and development services and also quite high in Information and communication technology (ICT) industries but much less frequent in Management, scientific and technical consulting services. A more detailed account by individual services industries presented in Appendix illustrates that there are important differences within the major service industries groups included in Table A-4.

Table 5. Internal Sources of Ideas for Technology Required for Innovation in Selected Service Industries, 2003 (% of innovators using a source)

Industry	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Reliability		%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
ICT	62.2	B	B	58.3	B	A	35.5	B	A	64	B	B	19.9	A	A
Management	33.4	B	B	31.6	B	B	36.7	B	B	68	B	B	19.4	A	B
R&D	88.3	B	B	45.2	B	B	24.6	B	A	56	B	B	18.9	A	B

Sector composition

ICT: Information and communication technology (ICT) industries

Management: Management, scientific and technical consulting services

R&D: Scientific research and development services

Source: Author's tabulation of data from Statistics Canada,
Survey of Innovation, 2003.

Surveys of innovation show that R&D activity is often the most important input in the innovation process, especially in the fields exploiting the most recent scientific progress. The most innovative firms combine information from internal R&D personnel with inputs from management, sales and marketing and production & production engineering. In addition, clients, suppliers, competitors, partners and collaborators of innovating firms also bring important contribution. The contribution of R&D personnel, and skilled staff and workers in other internal and external functions differ greatly from sector to sector and even within sectors from industry to industry. It also varies with the size of the firms and type and originality of innovation.

The existing innovation surveys were not designed with a primary objective of identifying and measuring the contribution of various categories of skilled labour end specialised personnel to innovation. However, some of the findings can be interpreted as indirect evidence regarding the contribution of various skilled labour categories to innovation.

Skilled personnel are hard to come by. Firms often cite the shortage of skilled personnel as one of the main obstacles in the innovation process. Active recruiting approaches and training are more often used by innovating firms than by the others. Baldwin (1999) overviews the studies he and his collaborators contributed to this issue. All studies came to conclusion that a large proportion of innovating firms find it difficult to hire and to retain skilled staff and workers. This conclusion should not, however, be construed as evidence that this problem is an exclusivity of innovating firms. Non-innovating manufacturing firms rate the difficulty to hire and to retain skilled personnel similarly as innovating firms.

Since Baldwin's paper to which I return in more detail below, Statistics Canada conducted two surveys of innovation, one in manufacturing industries (Statistics Canada, 1999) and one in selected service industries (Statistics Canada, 2003). The information from the 1999 Survey, regarding the skilled personnel is resumed in Table 6 below. It shows that almost two thirds of manufacturing firms, irrespective whether innovating or not, (the differences between the two are not significant) have difficulties hiring qualified staff and workers. Retaining the skilled personnel appears somewhat easier.

The successful innovating firms develop a range of competencies that help them to devise winning strategies. Prominent among the success factors are human resources strategies aimed at easing the shortage of skilled personnel by training and hiring. Training is the most popular remedy considered important or moderately important by 82% of innovating firms. The most frequent target for recruiting are experienced employees (71.2%). Innovating firms gave it moderately high or high importance), followed by recruitment of graduates of technical schools and colleges (42.6%). The next best strategy is hiring university graduates (24%). Only about 10% firms were hiring skilled personnel from abroad. These are averages for the manufacturing sector. They cover significant inter-industry differences as can be seen in detail in Appendix.

The lack of skilled manpower was and still is a serious and frequent impediment to innovation for 41.3 percent of innovating firms in the 1997-1999 period. It is reported more frequently by those firms that introduced the most original world first innovations. More than half of the world-first innovators (60 percent) reported that lack of skilled personnel constituted an impediment to their innovation in the 1989-1991 period (Baldwin and Hanel, 2003, p.211). According to the Survey of Innovation (1999), the proportion of the world-first innovators that reported this particular impediment to their innovation activity was 43% (Cozarrin, 2003, 193)[15]. Owing to significant methodological differences between the target populations and the sampling of the two innovation surveys (1993 and 1999), their results can not be meaningfully compared, but they underline the importance of the skill shortage especially for the most original innovators.

	Yes	Importance				
		Low	Moderately low	Medium	Moderately high	High
Lack of skilled personnel	41.3					
It is difficult to hire qualified staff and workers		3.6	10.8	21.6	33.6	30.4
It is difficult to retain qualified staff and workers		7.4	25.3	32.3	24.8	10.2
Hiring new graduates from universities		18.1	25.2	32.4	18.6	5.8
Hiring new graduates from technical schools and colleges		8.8	18.1	30.5	30.8	11.8
Hiring experienced employees		1.9	6.8	20.1	44.4	26.8
Recruiting skilled people from outside of Canada		47.9	26.7	14.9	6.6	3.8
Training employees		0.6	2.7	14.3	41.0	41.4

Table 6. Lack of Skilled Personnel and Human Resources Related Strategies, Innovating Firms in Manufacturing (% of innovating firms)

Source: Statistics Canada, Survey of Innovation 1999, Manufacturing

As regards the skill shortage impact on innovation in services that were surveyed in Survey of Innovation, 2003, the problem is reported less frequently than in manufacturing. The percentage of innovating firms that reported shortage of skilled personnel as an important or very important obstacle to innovation is in the 10-25% range (Statistics Canada, CD Innovation Survey 2003).

[15] Cozarrin (2003)reports that 60.2 % of world-first innovators reported to be “unable to devote staff” to innovation projects, the most frequently cited obstacle to innovation by the world-first innovators. I have difficulty interpreting the precise meaning of this question and how to relate it to the shortage of the skilled personnel.

Contrary to a sometimes popular belief that modern technology leads to ‘deskilling’ of workers who work with the ever more automated equipment, firms that innovate need skilled personnel able to successfully introduce new and improved products and processes on the market. Once introduced, these innovations have a skill enhancing impact on the users and adopters. As often in economics, it is difficult to disentangle the cause and the effect in this basically interactive process.

Another problem arises from the insufficient information on the actual use of professional skills and received education. Given the lack of direct evidence on the actual use of skills and qualifications in the innovation process, the possibility arises that the alleged skill shortages are, in fact, only artificially defined qualification shortages as proposed by the ‘credentialing’ or the ‘screening’ theories of human capital.

According to the ‘credentialing’ argument, the skills demanded by employers do not match actual skills used by employees. As the supply of educated labour expands, employers respond by raising the level of qualifications required to enter the increasingly wide range of occupations. Education does not have an effect on productivity (Berg 1970). The ‘screening’ argument accepts an indirect relationship between education and productivity but assumes that educational qualifications only serve as indicators of a very general kind of cognitive capacity – learning or training capacity (Spence, 1973). See Nahlinder and Hommen (2002) for a brief mention of these theories in the context of relationship between innovation and the human capital up-skilling.

Numerous macroeconomic studies concluded that technological change is biased toward skilled manpower (see the section above for details). This implies that it can be expected that innovations have a skill-increasing impact. The information available from the 1993 survey shows that indeed over the 1989-1991 period almost two thirds of innovators indeed reported that innovation increased the skill requirements of workers as well as their employment, especially in the category of non-production workers (Table 7). Similar results emerge from 1996 Survey of Innovation in dynamic services. Over 30% firms in financial services, business services and communications reported that their innovation increased skills requirements.

Table 7.
Effect of Innovation on the Number and Skill Requirements of Workers in the Firm (% of innovating firms)

Effects	Decrease	Increase	No change
number of production workers	12.5 (1.5)	35.5 (2.2)	49.0 (2.3)
number of non-production workers	3.9 (0.9)	23.4 (1.9)	58.5 (2.2)
skill requirements of workers	0.8(0.4)	60.3 (2.2)	38.4 (2.2)

Source: Baldwin and Hanel (2003, Table 6.7, p144)

Several studies conducted by the Microeconomic Analysis Division of Statistics Canada have examined selective aspects of the demand and supply of the skilled personnel involved in the innovation process. Baldwin (1999) provides a useful overview of the earlier work, much of it his own and his colleagues', based on several Statistics Canada surveys.[16]

Among important conclusions of that overview is that the small and medium sized firms feel that skilled labour is one of the most important factors contributing to their growth. Its importance is second only to management.[17] Training is recognized as one of the leading success strategies. Some 52% of firms have either formal or informal training programs; 36% have formal training programs. In contrast, only 10% of firms report employment in an R&D unit or investment expenditures devoted to R&D. While firms tend to place more emphasis on H.R. strategy than on their innovation strategy, the latter is the key factor associated with growth. The successful manufacturing firms tend to place greater emphasis on innovation strategy based on R&D and development of new technologies. In business services industries more successful firms focus on technological capability - the improvement of technology. In construction industry it is improvement of technology and in natural resource industries the emphasis is on developing refinements in the technology purchased from suppliers.

[16] This section is based on Baldwin's survey of Statistics Canada work on HR in innovation and adoption of advanced technologies (Baldwin (1999)

[17] As reported by the management.

Human resource strategies (hiring of skilled labour, continuous staff training, innovative compensation packages or a combination thereof) are not statistically related to success in manufacturing, but they are in services.

(Baldwin and Johnson, 1996) and Johnson (1996) show close connection between training, labour skills, and innovation. The top innovators in the highest quartile of the small and medium size growing firms have training programs (80%) while only 36% in the bottom quartile have one. The difference is much more important in services! In manufacturing, but not in services, training is also positively related to increases in capital intensity. This is so because in manufacturing training is also associated with development of new technologies and with the use of new technologies (new machinery and equipment. In services the capital essential to innovation is more likely to reside in human form.

Training expenditures per employee for the more successful product innovators are higher than for the less successful product innovators. Among the comprehensive innovators, i.e. those firms that introduced product innovations requiring modifications of manufacturing technologies, the more successful are more likely to have formal training program. Among process innovators the trend is similar but the difference is not statistically significant.

Skill shortages reported by innovating firms

Over 46% percent of manufacturing firms reported in 1999 that a lack of skilled personnel acts as an impediment to innovation, significantly more than lack of information on markets, on technical services, or interfirm co-operation. Lack of skilled personnel is reported as being an important impediment by 22% of innovators in communications and 30% in business services. It is less frequent in financial services. Adoption of advanced technologies increases education and training costs; in Canada slightly more than in the U.S. Skill shortages are always higher in firms that are more "innovative" (e.g world-1st innovators > Canada-1st innovators > other innovators). The users of advanced technologies in manufacturing and also in services are more likely to encounter skilled worker shortages than the non-users.

The situation may be different in new firms as opposed to in established firms. Faster growing entrants are more likely to emphasize training, the recruiting of skilled employees and competitive pay packages than the established ones. In a subsequent paper Baldwin (2000) looked at firms entering an industry[18], why some thrive and other fail and how their performance is related to innovativeness. The position of the innovator in the life cycle determines the type of innovation, which in turn strongly influences the rate of growth. The combined product-process innovators are most likely to be in the highest growth category (70%). Product innovators are second (59%), process innovators are third (49%) and less than half of non-innovators (43%) are found in the top half of firms ranked by rate of growth. The results suggest that product innovators have to worry more about training because the skills required of the work force in the early stage of the product life cycle have to be developed internally rather than acquired externally.

Closer to our subject, the paper also explored whether and how firms' emphasis on recruiting and training of skilled personnel contributes to innovation and to growth. Was it innovation itself that led to growth or skill emphasis? Or was the difference in skill emphasis and its relation to growth simply caused by the fact that innovators are in the faster growth class and innovation requires a special type of human-resource strategy? The response depends in part on the industry sector. When the sample is broken down into goods producing firms and services, the innovation variable is significant in the goods producing industries, while the reverse is true for the skills variable. This confirms Baldwin and Johnson (1996). Innovation is seen more important in "high" knowledge industries but labour skills are equally important in « high » and "low » knowledge industries. Baldwin concludes that entrants that train are more likely to grow irrespective of the emphasis that a firm places elsewhere on innovation and technological capabilities.

Are there differences between innovators and users of advanced technologies with regard to skilled personnel?

Both innovators and firms that adopt advanced manufacturing technology report problems related to skill shortage. The distinction between the two categories is often blurred.

[18] Based on S.C. Survey of Entrants, conducted in 1996. The sample included 3991 firms both from goods producing sector and services. The frame consisted of a longitudinal Dbase of firms 1983-1986 that survived to 1993.

Baldwin and Peters (2001) examined the ways innovation status and technology use affect training activities of manufacturing plants.[19] The authors found that :

> “ innovation requires new skills that are not so much occupation specific, but rather general cognitive skills that come from operating in an innovative environment that requires improved problem-solving capabilities by many different members of the workforce. These occur in learning-by-doing setting -with hands-on experience…..…Innovative firms meet problems that have to be solved and report theses impediments more frequently then non-innovators. As a response to this, innovators train their personnel to solve these problems by firm specific training.

In contrast:

> “(advanced) technology users and non-users regard skill shortages as equally problematic impediments. But technology users are more likely to regard training as an impediment. This is an activity that they use more intensively as a solution for skill shortages. The problems that they recount as impediments arise from their more intense training activity”.

According to (Sabourin, 2001)’s analysis of the Survey of Advanced Technology in manufacturing conducted in 1998, three quarters of Canadian manufacturing establishments use at least one advanced technology (various new computer-based technologies). The adoption rate doubled in the five year period ((Baldwin and Lin, 2001). Occupational shortages were less severe in the early 90s ((Baldwin and Peters, 2001) when labour markets were experiencing a recession and when the use of advanced technology was less widespread. Firms that experienced labour shortages in the late 90s seem to consider them a more serious impediment to technology adoption than firms that reported this problem in the early 90s.

The 1998 Survey of Advanced Technology inquired about the type of skills used and found lacking by advanced technology adopters. Occupational skills shortages were most important (in decreasing order) for Professionals (42% of establishments), Skilled trades (40%) Technicians (37%) and management (31%). The shortage was also marginally more frequent in foreign owned plants than in plants owned by Canadian interests; it was increasing with the increasing number of AMT used and with the percentage of total investment invested in AMT.

The most intensive users of AMT are most likely to encounter skill shortages. But they are more likely to take remedial actions and no less likely to adopt AMT. While hiring is essential, training is an important complement ((Baldwin et al., 1996), 1997; Baldwin and Sabourin, 1997), 1996) have

[19] Based on the SC 1993 Survey of Innovation and Advanced Technology

shown that AMT users invest more in training than non users. Since at the end the innovators and adopters of advanced technologies have overcome the skill shortages, it would be interesting to find out the percentage of firms that have not innovated or have not adopted advanced technologies owing to the lack of skilled personnel. Unfortunately, this information is not available.

Recently Statistics Canada launched the Workplace and Employee Survey (Statistics Canada, 2001, Workplace and Employee Survey Compendium, Catalog 71-585-XIE) which is creating a promising data base that will provide a source of new information relative the skill and occupation mix involved in innovation activities, adoption of new technologies and organizational change. So far no studies examining the relationship between innovation and skilled personnel have been completed, but the data for some interesting projects is collected.

9. Discussion and conclusions

What can be concluded at the end of our quest for a magic recipe for a combination of skills needed for successful innovation?

First, the innovation literature does offer very little in terms of concrete general information. I see several reasons for this lack of information:

- The concept of innovation used in today's empirical research is too large. It ranges from revolutionary world-first breakthroughs to minor improvements of an existing product or process by the last imitator. Even though both radical and incremental innovations matter for economic growth, they are representative of very different situations and demand very different mix of skills.
- Introduction of a standard survey of innovation based on the Oslo Manual has increased international comparability of some aspects of innovation, such as innovation sources and effects. However, based on the large, "fit all" definition of innovation, the survey questionnaire is too blunt a tool to answer more pointed questions such as those relative to the mix of occupations and qualifications used in the innovation process.
- As the history of technology and various cases studies show, the radical and incremental innovations are both inseparable components of technological progress. As technological opportunity becomes ever more tied to scientific progress, R&D is

likely to become even more routine activity than in the past. The demand for engineers and scientists is growing and will continue to do so. The mix of those two forms of human capital is likely to reflect, to a certain degree at least, the 'division of labour' between research and development in the private and public sectors.

However, introduction of new products and processes on the market requires different skills and talents than painstaking exploring and experimenting so typical of many R&D activities. As the information on sources of innovation shows, marketing, sales and production staff intervene in the innovation process. As argued by von Hippel, the functional source of innovation vary among users, manufacturers and suppliers, according to the technical field and nature of innovation. The successful innovating firms are those that combine a broad range of competencies under an inspired and knowledgeable management.

- Access to and capability of exploiting various forms of agglomeration and knowledge spillovers, be it at the urban, regional or national level, play an important but still largely insufficiently explored role. The relationship to the skills involved in this process is a promising field for further research.

There is no doubt that there is an increasing need for refined information on specifics of skills, occupation and educational attainment involved in the innovation process. Introduction of long term joint work-place & employees surveys appears as a promising innovating response to this need. It can be expected that the fashion and demand for benchmarking will also eventually lead to inclusion in innovation surveys of questions regarding the skill and qualification mix in the innovation process. However, one has to be suspicious of its utility if used out of national and industry context. This may be particularly touchy in case of innovation in services given their heterogeneity and close relationship with human capital.

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Appendix

Table A-1

Importance of Internal Sources of Innovative Ideas by Industry

(% of innovators using the source)

Sector	Internal Sources (% of firms)				
	Management	R&D	Sales & Marketing	Production	σ*
	1	2	3	4	
Core					
Electrical Equipment[1]	45	68	45	25	6
Chemicals & Pharmaceuticals	44	72	54	17	6
Machinery	47	46	40	22	6
Refined Petroleum & Coal	58	60	24	21	12
Secondary					
Rubber and Plastic	49	49	49	47	8
Primary and Fabricated Metal	51	40	47	43	7
Transportation Equipment	56	50	36	42	8
Non-Metallic Mineral Pdcts	63	49	33	70	10
Other					
Food, Beverages, and Tobacco	64	34	46	28	5
Leather & Clothing	42	17	37	64	11
Textiles	40	42	36	39	10
Wood, Furniture and Fixtures	62	156	16	35	10
Paper & Allied Pdcts	48	32	63	39	9
Printing & Publishing	49	9	32	52	10
Other	71	48	52	39	13

Source: Baldwin and Hanel (2003)

Note: 1) Includes instruments

2) * the standard error σ is the average for standard errors in the same row.

Table A-2. Sources of Innovation Ideas, Manufacturing, 1999

Industry	Internal sources of information									
	R&D		Marketing		Production		Management		Other sources	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	53.4	A	66.4	A	72.5	A	76.9	A	14.7	A

Industry	External sources of information															
	Related firms)		Suppliers		Clients		Competitors		Consultants		Universities		Fed. Res.labs.		Prov.res.labs	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	35.9	A	65.4	A	65.4	A	36.3	A	19.2	A	8.5	A	8.7	A	5.6	A

Industry	Generally available sources of information							
	Trade fairs		Internet inform.		Conf. & Publications		Other sources of information	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	68.9	A	38.2	A	51.1	A	8.7	A

Source : Author's tabulation from: Statistics Canada, *Survey of Innovation in Manufacturing*, 1999,C

Table A-3. Internal Sources of Innovation, 1999

(% of innovating firms)

Industry (Manufacturing)	Internal sources of information									
	R&D		Marketing		Production		Management		Other sources	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Food	65.5	A	77.1	A	73.5	A	80.9	A	17.2	A
Beverage & Tobacco Product	59.7	A	81	A	84.8	A	80.1	A	19.3	A
Textile Mills	70.1	A	76	A	72.1	A	64.5	A	18.7	A
Textile Product Mills	37.8	B	72	B	63.7	B	66.8	B	7.8	A
Clothing	43.1	A	60	A	75.5	A	74.1	A	8.6	A
Leather & Allied Product	62.5	B	56	B	59.2	B	54.3	B	9.9	B
Sawmills & Wood Preservation	24.6	A	50	A	78.2	A	80.8	A	11.5	A
Veneer, Plywood & Engin. Wood Product	38.5	B	65	B	83	A	85.1	A	19.9	B
Other Wood Product	30	B	55	B	69.4	A	76.1	A	10.7	A
Paper	53.3	A	75	A	75.1	A	77.1	A	16.5	A
Printing	25.4	B	54	B	71.4	B	79.3	A	8.2	A
Petroleum & Coal Products	65	A	68	A	82.5	A	75	A	20	A
Chemical (excl. 3254)	76.7	A	76	A	70.6	A	64.5	A	16.4	A
Pharma. & Medicine (3254)	78.6	B	71	A	69.9	B	68.2	A	10.3	A
Plastics & Rubber Products	63.3	A	71	A	79.5	A	76.6	A	19.1	A
Non-Metallic Mineral Products	43.8	A	67	A	74.5	A	79	A	15.3	A
Primary Metal	51.5	A	62	A	87.1	A	82.9	A	17.8	A
Fabricated Metal Product	43.5	A	58	A	67.5	A	79.4	A	13.5	A
Agricultural, Construction and Mining + Industrial Machinery (3331 & 3332)	73.7	A	83	A	58.7	A	77.1	A	21.5	A
Machinery (excl. 3331 & 3332)	60.3	B	67	A	73.5	A	76	A	12.6	A
Computer & Peripheral Equip.	82	B	83	B	38.8	B	85.3	B	9.7	A
Communications Equipment	86.3	B	81	B	54.7	B	66.3	B	15.5	A
Audio & Video Equipment	x	A	x	A	x	A	x	A	0	A
Semiconductor & Other Electronic Equipment	66.2	B	77	B	68.8	B	93.3	A	22.7	A
Navigational, Measuring, Medical & Control Instruments, Magnetic & Optical Media	73.4	A	74	A	66.6	B	76.4	B	17.5	A
Electrical Equipment, Appliance and Component	70	A	81	A	70.6	A	76.5	A	19.1	A
Motor Vehicle, Body & Trailer, Parts	66.1	B	57	B	70.5	A	80.9	A	19.1	A
Aerospace Product & Parts	50.8	B	50	B	79.6	B	82.6	B	30.5	B
Railroad Rolling Stock, Ship & Boat Building	56.5	B	68	B	81	B	88.4	A	15.5	B
Furniture & Related Products	44.6	A	62	A	74	A	76.6	A	11.6	A
Miscellaneous	53.1	B	66	B	76.7	B	73.2	B	13.7	A
Total Manufacturing	**53.4**	**A**	**66.4**	**A**	**72.5**	**A**	**76.9**	**A**	**14.7**	**A**

Source : Author's tabulation from:
Statistics Canada, *Survey of Innovation,Manufacturing*, 1999,CD.

Table A-4 Internal and External Sources of Innovation Ideas, Manufacturing, 1999 (% of innovating firms)

Industry	Internal sources of information									
	R&D		Marketing		Production		Management		Other sources	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	53.4	A	66.4	A	72.5	A	76.9	A	14.7	A

Industry	External sources of information															
	Related firms)		Suppliers		Clients		Competitors		Consultants		Universities		Fed. Res.labs.		Prov.res.labs	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	35.9	A	65.4	A	65.4	A	36.3	A	19.2	A	8.5	A	8.7	A	5.6	A

Industry	Generally available sources of information							
	Trade fairs		Internet inform.		Conf. & Publications		Other sources of information	
	%	Reliability	%	Reliability	%	Reliability	%	Reliability
Manufacturing	68.9	A	38.2	A	51.1	A	8.7	A

Source : Author's tabulation from: Statistics Canada, *Survey of Innovation in Manufacturing*, 1999,CD.

Table A-5 Sources of Ideas for Innovation, Selected Service Industries

(% of innovating firms)

Industry	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
ICT	62.2	B	B	58.3	B	A	35.5	B	A	64	B	B	19.9	A	A
Management	33.4	B	B	31.6	B	B	36.7	B	B	68	B	B	19.4	A	B
R&D	88.3	B	B	45.2	B	B	24.6	B	A	56	B	B	18.9	A	B

Industry	External sources of information																							
	Suppliers			Clients or customers			Consultants			Competitors			Universities			Fed. Res. Labs.			Provincial Res.labs.			Priv.Non-profit Res. Labs.		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
ICT	47	B	A	81.4	B	B	12	A	A	34	B	A	6.2	A	A	2.3	A	A	1	A	A	1.5	A	A
Management	45.7	B	B	74.8	B	B	17.1	A	B	26	B	A	14.7	A	A	2.8	A	A	1.7	A	A	2.3	A	A
R&D	33.9	B	B	71.3	B	B	18.4	B	A	33	B	B	46.1	B	B	14	A	B	7.7	A	A	9	A	A

Industry	Generally available sources of information														
	Conferences, journals			Trade fairs			Trade associations			Internet			Other		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
ICT	42.3	B	A	40.6	B	B	24.3	B	A	62	B	B	3.2	A	A
Management	57.4	B	B	39.3	B	B	33.8	B	B	51	B	B	5.9	A	A
R&D	64.7	B	B	39.2	B	B	31.7	B	B	62	B	B	6.8	A	A

ICT:	**Information and communication technology (ICT) industries**
Management:	**Management, scientific and technical consulting services**
R&D:	**Scientific research and development services**

Source : Author's tabulation from:
Statistics Canada, *Survey of Innovation, Selected Services Industries ,2003*, CD.

Table A-6 Sources of Ideas for Innovation, Selected Service Industries

(% of innovating firms)

Information and communication technology (ICT) industries	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
Computer & com. equipment & supplies wholesaler	35.5	B	B	67.8	B	B	32.9	B	B	77.8	B		18.4	B	B
Office & store machinery & equipment wholesaler	44.2	E	E	68.2	B	E	24.9	E	A	50.7	E	E	39.9	E	B
Software publishers	89.1	B	B	59.2	B	B	38.7	B	B	69.3	B	B	14.2	A	B
Wired telecom. carriers	62.1	E	B	61.5	E	B	62.7	E	B	85.4	B	B	46.9	E	A
Wireless telecom. carriers (except satellite)	23	A	B	72.5	B	B	7.4	B	A	81.6	E	E	21.4	B	B
Telecom. resellers	49.3	A	E	93.1	E	E	32.7	B	E	100	E	E	32.7	B	E
Satellite telecom.	40.5	A	B	33.2	A	B	22.1	B	A	100	B	B	31.4	B	B
Cable & other program distribution	48.1	B	B	54.3	B	B	16.9	A	B	74.1	B	B	27.6	A	B
Other telecom.	x	A	A	x	A	A	x	A	A	x	A	A	x	A	A
Internet service providers	57.4	B	B	78.3	B	B	41.7	B	B	76.9	B	B	9.1	B	A
Web search portals	x	A	A	x	A	A	x	A	A	x	A	A	x	A	A
Data processing, hosting, & related services	52.3	B	B	53.7	B	B	39.6	B	B	59.7	B	B	19.7	B	A
Office machinery & equipment rental & leasing	28.8	A	E	14.2	B	A	42.9	E	A	28.8	E	A	0	A	A
Computer systems design & related services	71.1	B	B	52.7	B	B	36.6	B	A	57.5	B	B	15.8	A	B
Electronic & precision equipment repair and maintenance	27.6	A	B	73.1	B	B	58	E	B	89.9	E	B	52.4	B	B

Total	**62.2**	**B**	**B**	**58.3**	**B**	**A**	**35.5**	**B**	**A**	**63.8**	**B**	**B**	**19.9**	**A**	**A**

Table A-6/continued

Selected professional, scientific and technical services	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
Engineering services	30.7	B	B	32.5	B	B	41.1	B	B	67.3	B	B	8.1	A	A
Geophysical surveying & mapping	37.3	B	B	40.5	E	B	36.9	B	B	28.5	E	E	28.5	B	B
Surveying and mapping (except geophysical)	44.3	B	B	31.7	B	A	52.2	B	B	67.8	B	B	18.4	B	B
Testing laboratories	35.9	B	B	49.5	B	B	31.3	B	B	55.9	B	B	14.9	A	B
Industrial design services	87	B	E	50	A	E	34.4	B	B	80.2	B	E	29.5	B	B
Computer system design & related services	71.1	B	B	52.7	B	B	36.6	B	A	57.5	B	B	15.8	A	B
Management consulting services	25.6	B	B	31.5	B	B	38	B	B	68.3	B	E	18.7	A	B
Environmental consultants	53.7	B	B	22.1	B	A	30.8	B	B	55.5	B	B	31.4	B	B
Other scientific & technical consulting services	55.6	B	B	38.7	B	B	35.3	B	B	73.3	B	B	31.4	B	A
Total (Management)	**33.4**	**B**	**B**	**31.6**	**B**	**B**	**36.7**	**B**	**B**	**67.6**	**B**	**B**	**19.4**	**A**	**B**
R&D in physical, engineering and life sciences	93.1	B	B	47.4	B	B	23.6	B	A	53.4	B	B	18	B	B
R&D in the social sciences and humanities	65	B	B	34.6	B	B	29.6	B	B	70.5	B	B	23.4	B	B
Total (R&D)	**88.3**	**B**	**B**	**45.2**	**B**	**B**	**24.6**	**B**	**A**	**56.3**	**B**	**B**	**18.9**	**A**	**B**

Table A6/ continued

Selected natural resource support	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
Support activities for forestry	49.9	E	B	10.4	B	A	42.1	B	B	49.9	B	B	16.3	B	A
Contract drilling (except oil and gas)	33.3	E	A	22.2	E	A	66.7	E	A	77.8	E	E	11.1	A	B
Other support activities for mining	52.6	B	B	57.9	B	B	63.2	B	B	84.2	B	B	42.2	B	B
Geophysical surveying & mapping	37.3	B	B	40.5	E	B	36.9	B	B	68.5	E	E	28.5	B	B
Surveying & mapping (except geophysical)	44.3	B	B	31.7	B	A	52.2	B	B	67.8	B	B	18.4	B	B

Selected transportation industries	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
Air	11.1	A	B	44.5	E	B	44.5	E	B	72.2	E	E	27.8	B	B
Rail	12.5	B	A	50	E	E	50	E	A	75	A	E	0	A	A
Water	60	B	E	50	E	E	20	A	E	80	E	E	40	B	E
Truck	26.9	B	B	42.3	E	B	73.1	E	E	92.3	E	E	30.7	E	B
Interurban and rural bus	0	A	A	0	A	A	14.3	E	A	100	A	A	0	A	A
Airport operations	10.5	A	B	15.8	B	A	42.1	B	A	68.4	B	B	10.5	B	A
Port & harbour operations	33.3	A	A	75	A	B	41.6	A	A	83.4	A	A	0	A	A

Other industries	Internal sources of information														
	R&D			Marketing			Production			Management			Other sources		
	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H	%	Rel MH	Rel H
Office & professional equipment wholesaler	34.3	B	B	76.3	B	B	20.9	B	B	70	B	B	26.2	B	B

Source: Source : Author's tabulation from: Statistics Canada, *Survey of Innovation, Selected Services Industries ,2003,* CD.