Public Research Organizations in the Knowledge Infrastructure*

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Introduction

Public research organizations (PROs), universities and public research laboratories, are important producers of new knowledge. Indisputable leaders in science related activities, they account for most of the output in basic research as well as a large fraction of applied research (Salter and Martin, 1999). To contribute to national priorities, such as job creation or regional development, this new knowledge must however be diffused to industry. Knowledge flows connecting PROs to industry are therefore essential to the exploitation of PROs' research output and largely account for policies devoted to university-industry relations as a priority in most industrialized countries. This also raises the issue of the spatial dimension of such interactions. Where do knowledge flows between PROs and industry occur? Which of the international, national, subnational or sectoral levels is the most fruitful for policies and for analysis? On the regional scale, an ongoing debate attemps to ascertain the actual and potential contribution of PROs to local industry (Vedovello, 1997).

The perspective adopted in this paper is that PROs represent an important actor in the environment of firms. Since no firm can develop alone all the knowledge required to innovate, it must establish a large network to access the stock of knowledge. This network implies an international, national, regional and sectoral dimension. At the regional level, the hypothesis is that firms share common resources. Local industry is wired to the same traditional infrastructure, such as transportation or communication systems, as well as to the same knowledge infrastructure. PROs are an important but not the sole actor of that knowledge infrastructure.

This paper deals with the role of PROs in the knowledge infrastructure on a regional basis. Data is derived from a project studying PROs-industry relations in Canadian materials and photonics research. The first part of the paper is devoted to the role of PROs in the knowledge infrastructure, while the second part raises the issue of the measurement of knowledge flows between PROs and industry. The third part presents data on regional interactions of PROs.

PART 1 : PROs and regional systems of innovation

National systems of innovation have been analysed according to various approaches (Edquist, 1997). Lundvall (1992) stressed producer-user interactions among firms and the learning process it represents. Nelson (1993) devoted his attention to national institutions and public policies which contribute to the innovative performance of national firms. Freeman (1988) developed an institutional perspective, sustaining that "the influence of the national education system, industrial relations, technical and scientific institutions, government policies, cultural traditions and many other national institutions is fundamental" (Freeman, 1995 : 5).

The concept of "national system of innovation" has been criticized for its heterogeneity and its weak theoretical underpinnings (Niosi *et al*, 1993; Cooke *et al*, 1998). The notion of "system" itself is exacting in as much as interactions effectively take various forms, including weak and irregular ties between parties (Cooke *et al*, 1997). It can be added that analysts of national systems of innovation have not really exploited the literature on network analysis, where organizations established relations in order to reduce uncertainties (Mizruchi and Galaskiewicz, 1993). Network analysts put emphasis on the exchange of information between organizations and its impact on the decisions.

The emphasis on the "national" level was also questioned on the ground that, on one hand, international flows of knowledge are certainly critical and, on the other, the subnational level appears particularly relevant to institutional development (OECD, 1997).

Common to all these approaches to national systems of innovation, and certainly their major contribution, is the emphasis given to knowledge flows. The assumption being that social benefits resulting from science and technology are not only associated with the production of new knowledge, but also with the scope of its diffusion. According to David and Foray (1996 : 87), "a key determinant of the economic performance of an innovation system is its capacity to effectively and efficiently distribute knowledge".

Furthermore, knowledge flows imply social interactions between actors and organizations. In that respect, institutions, defined as beliefs, cultures, routines, procedures, conventions, roles and organizational forms (March and Olsen, 1989 : 22) play an important role and must be scrutinized since they govern relations between individuals and their organizations (Edquist and Johnson, 1997). Although frequently associated with rigidity, they do provide incentives to innovate, as witnessed by innovation policies and property rights. Inclusion of institutions greatly enlarges the scope of the study by adding actors and organizations not directly related to the production of knowledge, but certainly influential in its diffusion. As mentioned above, the educational system is obviously crucial among such institutions.

It should be added that the "diffusion" of the "national system of innovation" framework from the academic world to the policy arena represented a major breakthrough in innovation policies. First, it has generated a far more sophisticated view of innovation. Second, it raised the complex issue of interaction among research organizations and knowledge diffusion. Third, it fostered the implementation of new policies promoting the latter.

Public research organizations (PROs), which include universities and public laboratories, emerged as an important component of national knowledge infrastructure. Tassey (1992) and Teubal *et al* (1996) favored an enlargement of the notion of infrastructure beyond the energy, transportation and communication sectors. The assumption being that technical change needs not only the traditional infrastructure, but also a science and technology component, which includes human capital (ex : pool of engineers), as well as institutional (ex : patent system) and technological infrastructures (ex : technology institutes) shared by the national industry. In industrialized countries, firms have access to such resources, either in the public or the private domain. According to Smith (1997), this knowledge infrastructure is essential, first, to the production and diffusion of scientific and technological knowledge, secondly, to education, training, and skill development, and, thirdly, to standardization, regulation and protection of technical activities.

PROs increase the stock of knowledge. The social benefits depend however on its diffusion. Government decision makers and PROs managers have implemented policies to foster interactions between PROs and firms. Two mechanisms are mostly used. First, policies sustain the creation of forums where PROs researchers and industry representatives can come in contact with one another. Secondly, financial and fiscal mechanisms have been implemented to increase the level of industrial funding of PROs research. The latter concerns a variety of leveraging mechanisms, consisting of contracts awarded by industry which are taken into account in the evaluation of research centers and whenever public funds depend on the level of private funding. The assumption behind these policies is that diffusion from PROs to industry is not automatic. Since it occurs through formal as well as very frequently informal interactions, the social and institutional dimensions are crucial especially for the latter and policies must target the reduction of existing barriers.

Starting in the late 1980s, private financing of PROs research has substantially increased in most industrialized countries (OECD, 1998). In Canada, the share of the private sector money in university R&D increased from 4% in 1987, to 12% in 1997 (Statistique Canada, 1998). Researchers and PROs managers have found strong advantages in their involvement with industry and their participation in public policies devoted to interactions with industry.

For researchers, the main incentive was access to increased funding (Meyer-Kramer and Schmoch, 1998). Furthermore industry's increasing involvement in scientific research in science-based fields fostered exchanges with PROs because cooperation resulted in the production of new knowledge. Such interactions with industry reflected PROs traditional mission, the advancement of knowledge. Meanwhile, industry's major motives were to keep abreast of the evolution of knowledge in their area, to learn new techniques and to recruit employees (Peters *et al*, 1998).

For PROs administrators, the incentive was not only to increase research funds, but also to demonstrate the industrial relevance of their organization. In the context of public budget cuts and disillusion over government intervention, there were strong pressure to gain support from outside actors. Lobbies were largely organized on a local basis, especially in order to obtain research funds from national governments. Starting in the 1970s with priority given to regional economic development, decisions tended towards the increase of science and technology investments outside large centers and the regional distribution of PROs. All this is in accordance with the emphasis put on knowledge diffusion. This dynamic led to competition among regions in order to influence the allocation of national funds.

Geographers were first to sustain that geographical proximity is important in knowledge diffusion (Cooke *et al*, 1998; Saxenian, 1991; Bianchi and Bellini, 1991). They observed strong industrial clusters on a regional basis (Baptista and Swann, 1998). This was further supported by the recognition that much of knowledge is uncodified and tacit, and must be diffused through direct interaction between individuals. Furthermore, most actors in a region are educated through the same education system and share a common culture. Local industry is also likely to have access to the same pool of consultants and suppliers. Firms located in areas where such resources are abundant are more likely to innovate (MacPherson, 1997). In other words, firms in a given region share various infrastructures including the conventional and the knowledge infrastructures.

Feldman and Florida (1994) have extended the idea of technological infrastructure on a regional basis. It includes three main components: a concentration of industrial and university R&D providing new ideas and invention; an agglomeration of firms in related industries contributing to the stock of expertise and tacit knowledge; and a network of business-service providers supplying information. According to them, the local dimension is important since "geographic proximity of these inputs promotes information transfer and spill-overs that lower the costs and reduce the risks associated with innovation" (Feldman and Florida, 1994 : 214).

PROs are certainly associated with the first component, although they are increasingly involved in activities typical of the third one. Due to the emphasis devoted in policies to knowledge flows, PROs and especially public laboratories have developed technical services as a tool to gain more direct access to firm and to foster diffusion of knowledge.

If this analysis supposes that PROs are important actors in regions, knowledge flows occur also on the sectoral, national and international level (Edquist, 1997). The choice of the level of analysis depends on two factors. First, for empirical analysis, knowledge flows have to be documented in order to determine how knowledge is diffused in any academic discipline and industry. For instance, Ehrnberg and Jacobsson (1997) listed industries which tend to develop strong interaction on a local basis. Secondly, each level corresponds to specific issues. For instance, the study of "national" system of innovations comes from the fact that our innovation policies and our knowledge infrastructure are largely national. Public laboratories were largely created as national institutions, the possible exception being those in the natural resources and, even if they have a national status, they find clients in specific regions. Financing of PROs came, and still comes largely, from national governments.

PROs also have strong international interactions. This is of course convergent with the development of the scientific enterprise, organized under international institutions for its diffusion and recognition, although financed through national funding. At first glance, such interactions are not contradictory with the role of PROs in the diffusion of knowledge to national and local industry. Participation in international scientific communities allows access to knowledge produced all over the world, and to diffuse it to local actors. Ties with foreign firms are however more problematic (DalpŽ, 1997). Governments of most industrialized countries have given public laboratories a mandate to promote formal interactions and diffuse knowledge only to local firms. Universities have a measure of freedom to determine whether researchers can have ties, and under what conditions, with foreign firms. Under severe budget constraints, PROs have some incentive to have link with large foreign firms.

Empirical analysis has shed light on this diversity of interactions. Concerning regional networks, studies on science parks indicate that a local industry may have loose ties with local PROs, while specific firms have closer ties with PROs located outside their region (Vedovello, 1997). Some links, such as those associated with manpower training or access to laboratories equipments, are often easier to establish with local PROs. Informal mechanisms benefit from geographical proximity, while formal interactions depend more on expertise.

PART 2 : Methodological Issues

The measurement of knowledge flows is a rather recent exercise. Existing science and technology indicators deal mainly with inputs, investments or manpower in research, or with outputs, measuring the stock of knowledge through, for instance, publications or patents. Knowledge flows are also difficult to trace because they are an intangible good, which one can follow only through its medium. Finally, they occur both through formal and informal mechanisms, the latter being difficult to monitor.

From a literature survey of empirical studies on the relations between scientific organizations and industry, Pavitt (1998 : 796) lists the seven major mechanisms through which scientific research contributes to technological problem-solving :

- useful knowledge inputs
- engineering design tools and techniques
- instrumentation
- trained scientists and engineers
- background knowledge
- membership of national and international professional networks
- spin-off firms.

These mechanisms cover a wide range of possibilities. On one end of the spectrum are indirect knowledge flows, such is the case most of the time for engineering design tools and techniques. They occur most frequently through intermediaries, such as consultants or students. For David *et al* (1992), most social benefits of basic research are derived from the exploitation of broad concepts and methodologies, where diffusion happens through indirect interactions. On the other end, researchers are directly involved in spin-offs.

Taking into account what is measurable and what is available in terms of science and technology statistics, the OECD (1997) establishes four types of knowledge or information flows :

- interactions among enterprises
- interactions among enterprises, universities and public research institutes
- technology diffusion
- personnel mobility.

The second and fourth types correspond to our study. *Interactions among enterprises, universities and public research institutes* depend on four main techniques :

- joint research activities. Administrative data gathered by PROs makes is possible to trace contracts and grants awarded by industry.
- co-patents and co-publications. Bibliometrics methods, coauthorship of publications or joint ownership of patents, are used as indicator of collaboration between organizations.
- citation analysis. Also through bibliometrics methods, references in industry generated patents or publications are scanned in order to determine whether industry exploits scientific literature and PROs patents.
- firms surveys. In questionnaires, industry representatives indicate the extent to which they consider PROs a source of knowledge. This technique leads to the detection of more informal networks.

The measurement of *personnel mobility* is a very recent preoccupation. The OECD (1997) favors the development of "labour market statistics", tracking personnel movement between PROs and industry.

In this study, three indicators were retained :
- co-publications. This indicator is derived from bibliometric analysis, which is the quantitative analysis of written documents. It is based on the assumptions that the scientific enterprise favors fast diffusion of research results to the community and that the system of recognition is based on peer review evaluation of the quality of publications. Bibliometricians developed publication databases including most important journals, those favored by researchers and their communities and where most significant new knowledge is published.

Coauthorship of a publication reveals a network of researchers in the production of a scientific output. Such interaction implies an exchange of expertise or data between researchers which result in the development of new knowledge. On a broader level, both organizations are therefore in interaction and other exchange of information is likely to take place.

Data was extracted from the *Science Citation Index*. As far as this database extensively covers scientific publications, but more rarely technical literature, data should be interpreted as interactions in scientific research.

- contracts. This indicator refers to formal research interactions between a contractor, a PRO, and a client, another public or private organization. This interaction implies that money is exchanged and that an agreement has been signed between both parties. This indicator measures therefore a very specific type of direct interaction. It has gained great policy significance because, as mentioned earlier, it emerged as a measure of PRO-industry relations and PROs relevance.

This data is extracted from administrative data. Its reliability depends on the quality of information systems. In this paper, we use two types of information on contracts. First, aggregated data appearing in official documents of the PROs. Second, data at the researcher level provided by university departments or divisions of research.

- advisory committees. In order to foster interactions between them and industry, most PROs were required to establish advisory committees. Their role is to indicate their opinion about the research program of the said PROs in order to orient research on industry's needs.

PART 3 : Knowledge Flows in Materials Research

Canadian policies in materials research

Advanced industrial materials are based on new knowledge resulting from pure and applied research in metallurgy, ceramics, solid-state physics, polymer chemistry and other disciplines (OECD, 1989). It emerged as a priority in most industrialized countries in the mid 80's. Advanced industrial materials included metals and alloys, ceramics, superconductors, advanced polymers, and semiconductor materials. Expectations were that new materials, such as ceramics or superconductors, would be progressively substituted for traditional materials, such as metals. The process was, for instance, in progress in the aerospace or sporting goods industries where performance, rather than cost, was the most important criterion.

The attention devoted to materials research was probably larger in Canada than in other countries because of the size of our resource-based industries. Also, more emphasis was put on traditional materials, such as metals and paper. Concerns were traditionally raised about the relatively low innovative activity and R&D spending of our industry (Britton and Gilmour, 1980). In such a resource-based economy, the potential development of new materials was considered as a threat. Canadian industry would not be capable of counting on its traditional advantages, the availability of resources, and would suffer a lot due to its major weakness, its low R&D spending. An additional question was that of the capacity of the Canadian industry to appropriate and exploit research results of the Canadian knowledge infrastructure.

Even if the Canadian Government officially listed advanced industrial materials among its science and technology priorities only in the late 80's, interventions in the area started in the late 70's (DalpŽ *et al*, 1999). For instance, the Industrial Materials Institute was created by the NRC in 1978. Materials research benefited from most policy initiatives implemented in the 80's concerning the knowledge infrastructure. For instance, a subprogram for materials research was added to NSERC strategic grants program in 1984.

This data is derived from a project consisting in the study of ten Canadian PROs created or restructured following these initiatives, and specialized in materials and photonics. The telecommunications industry was linked to several of these initiatives for projects related to applications of materials research to communication technologies. Photonics refer to advanced light-based technologies as the basis for information communication.

These ten PROs are :

- two public laboratories of the NRC : the Industrial Materials Institute (IMI) and the Institute for Microstructural Sciences (IMS). The former, created in 1978, is devoted to materials processes. The latter, in photonics, was established in 1990 after the reorganization of the Division of Physics. In accordance with policies of that period, it represents a shift from a disciplinary up to a topic structure.

- two federal Centres of Excellence : the Centre of Excellence in Molecular and Interfacial Dynamics (CEMAID) and the Centres of Excellence on Microelectronic Devices, Circuits and Systems for Ultra Large Scale Integration (MICRONET). Both were established during the first wave in 1990. The former was shut down in 1995 when the grant was not renewed.

- two university research centres in QuŽbec : the Centre d'optique, photonique et laser (COPL) and the Centre de recherche en sciences et ingŽnierie des macromolŽcules (CERSIM). Both benefited from the 1984 QuŽbec Government program *Actions structurantes*, which sustained university research teams in strategic sectors.

- a research consortium in the Western provinces : the Telecommunications Research Laboratories (TRLabs), established in 1984. Founder members were Bell Northern, the Government of Alberta and the University of Alberta. More recently, Manitoba and Saskatchewan Governments and their universities were also integrated.

- three Ontario Centres of Excellence : the Ontario Centre for Materials Research (OCMR), the Telecommunications Research Institute of Ontario (TRIO), and the Ontario Laser and Lightwave Research Centre (OLLRC). Created in 1987, these centres were greatly transformed in 1997.

The NRC institutes and both federal centres of excellence have a national orientation. For instance, the mission of IMS is "to provide leadership, in collaboration with Canadian industry, in the development of the strategic base for information technology" (IMS, 1993: 5).

Policies at the root of the six remaining PROs were provincial initiatives. The *actions structurantes* in QuŽbec were designed just before the policy era of university-industry relations, and the two centres in our sample remained less involved with industry than their counterparts from other provinces. The diffusion of research results to local industry never emerged as an important issue in this program. TRLabs, although a Western Canada based organization, does not have an explicit regional orientation concerning its industry relations. TRLabs mission is to "contribute trained people and innovative technology to achieve : economic growth for our government sponsors, business growth for our industry sponsors, academic and research growth for our university sponsors, and personal growth for our staff"(TRLabs, 1995 : 1). TRLabs benefit from a federal grant and are involved in a number of large national research projects and consortium, so that some of their partners have a national orientation.

Only two Ontario Centres of Excellence, OLLRC and OCMR, clearly have a regional-basis orientation. For instance, the mission of OLLRC is "to support outstanding laser and lightwave research that enhances the knowledge base in Ontario and provides the foundation for technology-based innovation ; to support industrial growth and wealth generation through partnerships with industries in Ontario and through technology transfer and diffusion ; and to train and develop highly skilled personnel to meet the needs of Ontario industry" (OLLRC, 1996). The third Ontario Centres of Excellence, TRIO, focuses on "Canadian telecommunications companies" (TRIO, 1994).

In the following presentation of data, we devote more attention to OCMR and OLLRC, being the two with a specific regional mission.

Co-publications

Extensive data is presented for OCMR. Publications of the 127 researchers in eight Ontario universities were gathered for 1995 and 1996. The largest concentrations of publications are in the University of Toronto (Depts of Chemistry and Materials), McMaster University (Depts of Physics, Eng. Physics and Materials) and the University of Western Ontario (Dept. of Chemistry). Slightly more than half of these 868 publications resulted from collaboration between research organizations, including interactions between two departments or research centres in the same university (Table 1).[1]

Table 1

The lowest level of collaboration, on a geographical basis, is intra-university cooperation, which occurs for 18% of the publications in our database (Table 1 and Figure 1). It is important to stress that it is

[1] The search was done in the *Science Citation Index*.

almost equally divided between two different patterns. The first one is the collaboration between two researchers affiliated with two different disciplinary departments. This pattern reflects the multidisciplinary character of material sciences research. In our sample, the most usual association of multidisciplinary research regroups researchers in physics and chemistry, followed by chemistry and chemical engineering. The second pattern concerns researchers associated with two different units. The most frequent case is the Brockhouse Institute for Materials Research at McMaster University, whose members are simultaneously affiliated with their home disciplinary department and this research organization. This research unit was created to favor the development of materials research and multidisciplinary research, and is the McMaster University counterpart of OCMR. Policies applied since the 80's sustained the creation of research organizations at the edge of the classic disciplinary departments. It is important to stress that these researchers, already associated with the Brockhouse Institute for Materials Research, do not identify OCMR as their research affiliation. They consider OCMR as a network of existing research organizations.

Figure 1

Collaboration between Ontario universities is however rather limited, slightly higher than with universities in other provinces (Table 1). The network of cooperation between Ontario universities shows the role of the two leaders, McMaster University and the University of Toronto, linked to almost all other players (Figure 1). Ties with universities in other provinces are with the leader in materials research, such as UBC and McGill.

A public laboratory, the NRC Institute for Microstructural Sciences (IMS), has interaction with most OCMR partners (Figure 2). Other public laboratories related to OCMR's researchers are AECL, Ontario Hydro and NRC's institutes IMI and Steacie. Two of these research organizations, IMS and IMI, are in our sample of PROs.

Figure 2

Concerning industry, 6% of the papers in our database are co-authored with an industrial researcher (Table 1). One firm, Bell-Northern, accounts for more than a third of these papers. Other firms are in electronics (Xerox), metals (Alcan and Cominco) and in transportation equipment (De Havilland).

Most of these public laboratories and firms are located in Ontario, in the Toronto or Ottawa areas. Only IMI is in Montreal, although with a national mandate. Concerning industry, it is important to stress that the three Canadian firms with the largest scientific output in materials research in Canada concentrate research activities in Ontario. They are Xerox, in polymer, Alcan, in metals, and Bell-Northern, in photonics. The latter has laboratories all accross the country, Ottawa and Toronto being the largest.

One-fourth of the publications in our database were co-authored with a foreign researcher (Table 1). They are mostly affiliated with a university or a public laboratory in the United-States, Japan or Western Europe. Research in cooperation with a foreign firm is rather unusual.

This data on OCMR is convergent with observation made for other PROs (DalpŽ, 1997). It can be summarized in four trends :

- four Canadian organizations are at the center of the network surronding OCMR's researchers. They all show a large scientific output and interactions with each other and with other research organizations in the area. There are two universities (McMaster University and University of Toronto), a public laboratory (IMS) and a firm (Bell-Northern).
- the research network integrates international actors. This reflects the international organization of scientific research, and the participation of Canadian actors in the international production of knowledge.
- industry participation is rather limited. This is explained by the low involvement of Canadian industry in scientific research dealing with materials. Three firms have interactions with the network, and of these Bell-Northern is a leader. Through its role as an industrial organization highly involved in research, this firm is the industrial partners of most PROs. This explain why photonics research benefited greatly from the policy initiatives of the late 80's and 90's.
- the leading Canadian organizations are located in the Toronto or Ottawa regions. Two other national concentrations are in the Montreal (IMI and McGill) and Vancouver (UBC and Simon Fraser). These organizations are loosely related to the OCMR network.

Contracts

Aggregated data appearing in PROs' official documents relative to contracts awarded to their researchers is used as an indicator of interaction with research users. Most PROs estimate that industry accounts for between 20% and 30% of total financing of research. The highest in our sample is TRIO, where it reaches 40%. At first glance, it reveals that the PROs in our sample were capable of generating a relatively high level of industrial money. This performance was at least good enough for their evaluators, the obvious exception being CEMAID which was not renewed in part because industrial benefits were considered too limited.

This data is however difficult to interpret taking into account the objective of this study. It is impossible to determine the geographical location of the client, or that of the contractor. Furthermore, as we mentionned in the previous section, because these organizations are really networks of other research units, it is difficult to trace the borders between these blurred organizations. Finally, each PRO gathers data according to its own administrative practices.

Data was generated on a departmental basis. We selected Canadian universities departments with the strongest involvement in materials research and in our ten PROs. Half of the departments surveyed offered reliable data. We retained all contributions from industry devoted to research, including contracts as well as grants, but not various in-kind contribution. Contracts awarded by the public sector or non-for-profit organizations were not retained. For instance, the Department of Chemistry at Laval University, which constitutes the core of the research centre CERSIM, has few contracts from industry, but many from the public sector. This pattern holds for researchers members of CERSIM who obtain contracts from various agencies of the Department of Defense, and non-CERSIM researchers benefiting from the same ministry and from Environment Canada. This data does not always make it possible to determine the exact geographical location of the firm since most university administrative data does not include a complete client address.

Table 2 indicates industry's share in research financing in these departments for the early and mid 90's. This share is still very small in four out of eight of our departments. There are strong variation among departments, revealing the concentration of industrial contracts and grants not only in a few departments, but also in the hands of a small group of researchers in each unit. For instance, in the Department of Materials in UBC, a group associated with an industrial chair accounts for the majority of contractual research. In our ten PROs, a similar concentration is frequent. For example, at the COPL in Laval University, the group most involved with industry is related to the Department of Electrical Engineering, and not with the Department of Physics which constitutes the core of this Centre.

Table 2

The share of industrial money increased in five of our eight departments, but decreased in two. The hugh increase shown by national data on university-industry contracts, from 4% in 1987 to 12% in 1997, does not materialize in most of our departments. This trend should be analysed very carefully. First, some of these researchers were already and for a long time involved in interactions with industry. Departments of metallurgy in United-States and Canada have a long tradition of close interactions with industry, which started long before the recent emphasis on university-industry relations. They were certainly ahead of most disciplines in the search of industrial partners in the late 80's.

Table 3 lists firms most involved through contracts and grants with UBC and McMaster University materials departments. In our sample, these two are the most specialized in materials research. It generates a longer list than in the previous section on co-publications because it corresponds to other forms of interaction. They are potential users of new knowledge, but most of the time not involved in its production. This allows them to generate clients in industries while demonstrating very limited R&D spending.

Table 3

Concerning the Materials Department of McMaster, its industrial clients consist of metals producers and users, almost all Canadian firms. A large fraction of industrial partners of the UBC Department are in the mining industry, including far more foreign companies. The leading group, specialized in hydrometallurgy and the evolution of metals in saline environment, developed a large network of users looking for that specific expertise.

Data on contracts can be summarized in three trends :

- contractual arrangements are of course established with firms, but also with public bodies. The network of users of research is not limited to the private sector. For instance, physics departments had much more contracts from the public rather than the private sector.
- contracts and grants with industry are very concentrated in a small group of researchers. Researchers most involved in contractual research are those also associated with other types of research organizations, such as the industrial chairs. This concentration implies that the expertise they have to offer is very specialized, and they can reach clients in a very large geographical environment.
- firms involved in contracts cover a much larger segment of industry what we saw for co-publication. Most firms are not carrying out R&D, and are only users of knowledge.

Advisory committees

The broad function of the advisory committees is to provide guidance on the orientation of research programs. While advisory committees of NRC's Institutes or sectors are limited to that mandate, others play a more active role in the selection of research projects or in managing technology transfers. For instance, OCMR has four types of committees : a Board of Directors, six sectoral Program Management Committees, a Scientific and Industry Advisory Committee, and a Scientific Program Committee. Micronet has a Board of Directors, a Business Development and Industrial Advisory Committee, and a Coordination Committee. We will concentrate our analysis on the Boards of Directors. Neither of Laval University's research centres have a structure equivalent to an advisory committee.

Extensive analysis was presented in another paper (DalpŽ *et al*, 1999). We list ourselves here to the most significant results :

- composition of these committees shifted during the early 90's, when participation of members from industry increased significantly and they now hold a majority of seats in all of these committees. The shift also affects the relation between these industrial members and the PROs. Some of them have established some type of industrial membership, and members of the Board of Directors are choosen within this list. Under such a system, for instance in the case of Micronet, only industrial clients have the priviledge to sit on the Board. Remaining members are representatives of the researchers or the public granting bodies. In the early 90's, some also counted researchers not associated with the PROs. For example, OCMR had on its board well-known materials researchers from other provinces or the US, their role was to evaluate the scientific quality of the research program. They are now relegated to a subcommittee, the Scientific and Industry Advisory Committee.

- two patterns emerged in regional distribution of members. The first one concerns the three Ontario centres of excellence and TRLabs. Members of their advisory committee are almost exclusively from their region. Even in the case of TRIO and TRLabs which have no specific regional mandate, board membership is very largely local. The second pattern regroups both NRC's Institutes and the two federal Centres of Excellence. IMI offers the more balanced regional dispersion, with most of its members from Quebec (7), but some from Ontario (4), and even one from Alberta and one from Nova-Scotia.[2] Micronet has seven members from Ontario, two from QuŽbec, one from Vancouver and one from Alberta. As far as PROs tend to choose industrial members among their most important clients, their committees reflect more directly the regional distribution of industrial activity. For instance, Micronet, dealing with the microelectronics industry finds four out of five of its industrial members in Ontario. It is rather difficult to find industrial representatives in Eastern provinces, so that almost all members from this part of the country come from universities. IMI shows a different regional distribution, partly because the membership of its board is more diversified since it includes representatives from another public laboratory, a QuŽbec government agency and two universities.

- the creation of advisory committees was a response to governmental policies in order to foster interactions between PROs and their users. Most PROs in our sample have choosen members among their clientele. The objective is to establish better relations with these very important partners, who in turn provide money. This generates not only an industrial network, but also a policy network. In all of these committees, whithout any exception, industrial representatives sit together with leading researchers, administrators of PROs, and policy managers. MICRONET and IMI, for instance, have different strategies in order to build their policy network.

Conclusion

[2] This data concerns IMI's Advisory Committee in 1994-95.

Measurement of knowledge flows in the knowledge infrastructure was done here through co-publications, contracts, and advisory committees. In as much as the diffusion of information cannot be measured directly, the assumption is that, when two organizations are in direct interaction, they are likely to exchange information and knowledge. Our indicators are proofs that such contacts do exist. Other measures are certainly required to get a more complete picture. According to us, the most obvious gap concerns personnel mobility. One of the most significant contribution of the knowledge infrastructure, and especially of universities, is certainly through formation.

Results were convergent with what we have learned from the regional innovation systems analysts. Our indicators do not show extensive and exclusive interactions with local industrial actors. For instance, scientific interactions, as witnessed by co-publications, describe a network of national and international organizations. Public policies have sustained the establishment of national bodies, while scientific communities are by nature international. Contracts indicate a mix of regional and national interactions. We can expect that technical services, which are not big business in our PROs, would have offered a more local network. Advisory committees, more influenced by the policy dynamics, more frequently adopt a regional orientation. Finally, formation would have constituted a more local profile of interactions between firms and PROs.

The construction of the network around PROs and their regional dispersion can be explained by policy and research dynamics. For some PROs, a local strategy is probably not viable. In materials and photonics, most major industrial players are located in the Toronto or Ottawa areas. PROs located outside these centres also have to interact with firms located in Ontario. Another important source of revenue for our PROs was the public sector. In telecommunications, most programs have a national orientation, and PROs are members of a Canadian network. PROs' success depends largely on the receptivity of firms. From our list of PROs, it is obvious that the telecommunications industry has largely fueled researchers, so that photonics emerged as an important topic. Telecommunications firms are themselves involved in research and have a tradition of interactions with PROs researchers. In metals, researchers get enough support to obtain the public counterpart, while, in paper, PROs have experienced notable difficulties.

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