Specialization Versus Diversity in Canadian Technological Development

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ABSTRACT. In the new era of liberalized North American trade one of Canada's goals is export-led growth in technology intensive activities. Macro-economic data show that technology intensive specializations are developing but their international success is limited. One reason is that business spends less on R&D in Canada than in most OECD countries. Problems associated with macro data have prompted the use of survey-derived data listing the high-technology products of firms in order to define technological clusters. Most of the firms comprising each cluster are small: the distribution of large producers and R&D labs and the structure of clusters are discussed. Aggregate and micro data are used to establish the localization of technology intensive industry, especially in the Toronto metropolitan region. This is the largest concentration of technology intensive firms and the importance of services as markets and as sources of technology intensive products is established. The conclusion weighs the importance of specialization versus diversity, small firm entrepreneurship versus the importance of large firms, and metropolitan attraction for high-tech firms vs. the chances of medium-sized urban centres.

Introduction

The stimulus for this paper is the anticipated structural impact of trade liberalization on Canadian industry (Britton, 1993; Drache and Gertler, 1991; Waverman, 1993). First, by seeking the Canada-U.S. Free Trade Agreement (1989) and then by participating in the design and implementation of NAFTA (1994), Canada has exposed its economy to a higher level of competition at home. It is assumed widely that this will have positive consumption effects through reduced prices. In production, the argument for trade liberalization has been that Canadian firms never have had secure access to the largest part of the North American market (the U.S.) and have been labouring under comparative disadvantages. In particular, the rate of technology adoption has been slow (Economic Council of Canada, 1987) and many low-skill manufacturing jobs have been preserved despite Canada's prevailing high wage-rates. Preferably, the educational attainment of the Canadian labour force would be reflected more strongly in the growth of activities (in all sectors) that rely on greater labour skill or intensity in the use of knowledge. Increased competition and marketing access are expected to have a strong impact on these characteristics of Canadian industry and technology-intensive activities take prime place in the knowledge-intensive economy that Canada hopes will be stimulated by trade liberalization.

The elaboration of the trade argument involving technology-intensive activities begins with the concept of technological innovation. The basic premise is that long-term rewards derive from the domestic generation and implementation of technology in the form of new designs, machines, components, services, and software. The ability of firms to design, produce and sell technology-intensive products is closely related to the process whereby new technology is adopted by other firms.[1] Canada has both a small economy and one which has been quite dependent on exports and open to international inputs of goods, services and capital. As a result, trade flows provide useful indications of the extent to which technological development relies on imported rather than domestic sources of technology and exports of technology intensive products help to clarify the extent to which industry has generated the ability to innovate.

Small economies, like Canada's, are under great pressure to become specialized in their innovation activity because of the substantial minimum scale

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of effort that is required to be successful in any one area of production (McFetridge, 1993; Soete, 1988). Small countries are further disadvantaged by the lack of diversity within high-technology sectors because the tendency is for few firms to be responsible for success. A corollary of these two facets of specialization is that Canada inevitably requires substantial technology imports even though the process of generating technology (indigenous innovation) provides opportunities for greater learning effects.

This is a critical issue because 70% of the assets of technologically advanced industries in Canada are controlled by foreign enterprises. Their choices have an important influence on the way the economy responds to trade liberalization. It should be noted, that these foreign companies are highly localized in the Toronto metropolitan region, the major concentration of technology-based activities, and thus ownership will be important when assessing the impact of trade liberalization on technology-intensive development.

Given the hopes of Canada that trade liberalization will provide these new opportunities and given the recency of NAFTA, this paper is very much an exploration of existing strengths: it provides a norm against which subsequent change may be evaluated. Its primary task is to identify Canada's technology-intensive activities and the locational foundations of that development. The core of the research reported here relies on the use of product data for individual firms in order to identify Canada's technological strengths. In broad outline, the approach seeks to define produce-based clusters which recognise coherent groupings of Canada's technology intensive companies. This information is then used to contrast the development of Toronto with that of Ottawa and some smaller but aspiring centres which also have very limited histories as industrial centres. While this micro-level examination of Canada's strengths helps to redress some of the limitations associated with the exclusive use of aggregate measures of industrial and trade performance, these macro data provide the appropriate material to establish an initial image of Canada's surprisingly weak technological development, and the opportunity to explain the industrial, trade and ownership context in which the examination of data on high technology firms takes meaning.

Basic parameters of Canadian R&D and trade performance

Research and Deveopment (R&D)

Although data on R&D expenditures measure an industrial input rather than an output it has proved to be a universally accessible indicator of participation in the innovation process. Canadian expenditures on R&D increased by 90% during the 70s and 80s (1971–88 in constant $) but this was not a competitive advance. Expenditures on R&D were only 1.4% GDP in 1990, just 0.1% more than the proportion in 1971! Other members of G-7, however, increased their expenditures substantially, the average of the ratios for Germany, U.S., Sweden and Japan increasing from 2.1% GDP (1974) to 2.8% (1990). This suggests Canada has under-invested in R&D for a long time: sectoral differences in the origins of Canada's GDP, and small R&D expenditures for defense[2] have some influence on R&D as does Canada's middle ranking in terms of the expenditure of public funds[3] on R&D.

A more detailed conception of Canada's technological development is provided by data on the research intensity of industries selected on the basis of their R&D/sales ratio in Table I.[4] Two sets of activities are relatively well-developed; Telecommunications equipment and the Aircraft and parts industries together account for 34% of R&D expenditures in manufacturing. The largest change in the industrial structure of the technology-intensive sector over the last decade or so comes from the increase in R&D expenditures in the service sector – from 14% to 27% of the Canadian total (1981–1991), indicating the increasing importance of software design and the growth of producer services as sources of technological competitiveness (Statistics Canada, 1990b; Industry Canada, 1994). While these gains appear to contrast sharply with the decline of expenditures in resource-based activities such as Mining and Oil wells (from more than 6% of total R&D to less than 2%), the largest performer of R&D among the services, Engineering and scientific services, is well connected with Canadian strengths in both resource development (for example, various energy production technologies) and transportation systems (especially urban transit).

TABLE I
R&D expenditures for selected[a] industries: Canada, 1991

Sector	R&D ($M)	R&D ($/Sales)[a]
Agriculture, fishing and logging	19	4.4
Manufacturing:		
Telecommunications equipment	655	22.1
Other electronic parts and components	38	8.1
Other electronic equipment	361	13.5
Aircraft and parts	445	13.0
Business machines	284	3.1
Machinery	90	3.4
Scientific and prof. equip	57	2.7
Pharmaceuticals and medicine	234	5.3
Other transportation equipment	145	8.4
Printing and publishing	10	2.5
Other manufacturing	28	2.8
All manufacturing	3205	1.8
Services:		
Engineering and scientific	423	18.7
Computer and related	234	17.9
Management consulting	32	7.2
Other services	52	4.5
All services	1304	1.6
All sectors	4853	1.9

[a] Industries were selected if R&D/Sales = or > 2.5% (1991).
Source: Industry Canada, 1994.

Technology-intensive *manufacturing* industries increased their share of industrial R&D from 49% to 64% (1975–1992) but the structural consequence of this growth on the output of the manufacturing sector has not been very large since high-technology industries contribute only 14% of manufacturing value added. There is considerable variance in the performance of individual industries with Telecommunications equipment, followed by Aircraft and parts, and Business machines, emerging from these comparisons as the most successful activities. At the other extreme, Machinery which is one of the smallest of these industries exhibits little of the dynamism that might be expected in a period when massive applications of microelectronics have been applied to the design of capital equipment to meet the demand for smaller scale, reprogrammable (flexible) production tools. The Drugs and pharmaceutical industry lies between these examples but it may be entering a period of some growth as a result of the sequence of federal increases in patent protection for new drugs. Some foreign proprietary drug companies have been induced to expand their R&D labs by the increased length of patent protection though this is likely to reduce the competition that can be offered by Canadian generic drug companies.

The primary explanation of the history of low expenditures on R&D and the limited Canadian exports of technology intensive products, lies in the behaviour of Canadian business. It is expected that Canada, a small country, will have a high degree of concentration of R&D among few firms (McFetridge, 1993) and it does since only 25 firms accounted for half the R&D performed in 1990 (NSERC, 1994) while another 465 firms are required to generate another 38% of R&D expenditures (Statistics Canada, 1989b). But concentration takes on more complex meaning when the high level of foreign ownership is considered: in manufacturing, 48% of current intra-mural expenditures on R&D (1990) were made by foreign firms (Statistics Canada, 1993).

About half the 100 largest performers of R&D are foreign subsidiaries thus raising an interesting question whether they have been attracted to opportunities in Canada that have not been realized by indigenous entrepreneurs or whether foreign direct investment grows through the takeover of indigenous firms. Probably both views have some validity (Corvari and Wisner, 1993). While foreign subsidiaries are important among the larger performers of R&D, the R&D/sales ratio provides a more appropriate basis for comparison since it controls for the influence of scale of enterprise on the amount of R&D expenditure. This ratio is much higher for domestic firms and the foreign R&D/sales ratio is only 5% of the Canadian level for Machinery and ranges between 35% and 77% of the Canadian level for Electronic parts, Other electronic equipment, Business machines and Drugs (Statistics Canada, 1993). This difference may reflect two influences. First, the access of subsidiaries to the technological resources of parent firms may result in a downward influence on foreign R&D/sales ratios since imports embody technological knowledge. Second, the high R&D intensity of small domestic firms may exercise an upward influence on Canadian ratios. This aspect of the technological development of Canadian industry points to an interesting level of entrepreneurial activity which is indigenous in origin but about which we know very little of a systematic nature.

Trade

The argument has been put forward in previous studies that there is a sustained connection between the low level of Canadian industrial R&D and Canada's lack-lustre performance in that part of its international trade which embodies substantial technological knowledge (Britton and Gilmour, 1978; Science Council of Canada, 1981). There is a surplus of C$10.2 billion in Canada's international merchandise trade[5] but this obscures an C$8 billion deficit component of the current trade balance (1991) generated by the excess of imports over exports of high-technology goods. The trade position is strongest in Telecommunications equipment and Aircraft and parts but it is weak in Computers, Machinery and Electronic equipment. A substantial deficit also exists in the services trade account which covers payments for consulting, royalties, and R&D – that is, there also appears to be a net transfer of technology into Canada by this means. Technological services add another C$2 billion to the goods deficit in Canada's technology-intensive trade account. The bulk of these net service payments are to U.S. affiliates and are prone to considerable underestimation since foreign parents often do not charge. The largest element of this negative balance involves royalties, patents and trademarks (Statistics Canada, 1990a).

These technology trade deficits are interpreted in much of the Canadian economic literature as a measure of Canada's *technology gap* with the rest of the industrial world (Britton, 1980). The net flows of technology into Canada are strongly influenced by corporate strategies through intra-corporate flows, alliances, and joint ventures and aggregate data for manufacturing indicate that the propensity of foreign firms to import is about 2.7 times that of domestic firms (Corvari and Wisner, 1993; see also Science Council of Canada, 1981, p. 95). The significance of intra-corporate imports hinges on the merits of two counter-posed arguments. The positive argument suggests that foreign firms bring R&D budgets and technology-based production. The other position argues that the effect of intra-corporate imports is to inhibit backward linkages to other Canadian technology-intensive firms and the developmental benefits that could derive from domestic sub-contracting and other user-supplier linkages. Data available for Canadian manufacturing do not allow full econometric tests of these hypotheses (Corvari and Wisner, 1993). Other evidence points to considerable variance in the behaviour of foreign companies. At one extreme, some have responsibility for product development from their Canadian base (Ontario Premier's Council, 1987) and anecdotal evidence suggests that some other subsidiaries are moving in this direction by narrowing their product-range and expanding their capacity to develop products. The more common direction of change, however, appears to be the transfer of some strategic functions to corporate head office. This process is related to the ease with which U.S. firms can now extend their supply systems across the common border.

Discussion

It seems fair to argue that the available macro data on R&D and trade take us only a limited distance in establishing the structure of new technology based industry in Canada. There are additional problems. Industry data binds our analyses to the uni-product conception of the output of firms – a characteristic of the way data are compiled to meet the definitions of the standard industrial classification – although we know that many produce a variety of different but related products. The implication of persisting with data files based on the standard industrial classification is that enquiry proceeds on the assumption that all firms in a designated industry meet some minimum standard of technological performance. It is highly desirable to avoid this unrealistic assumption and to acquire data that reveal the presence of technologically progressive firms, regardless of industry.

Another important limitation of industrial data is that the aggregate ratios of R&D/sales obscure the identity of activities in which technologically advanced products are being made either by a small proportion of firms or by firms whose R&D expenditures are too small to influence the industry total. We get some idea of the significance of this problem when we consider that only 64% of Canadian R&D is performed in the technology intensive activities identified in Table I. Two sets of very interesting firms are often overlooked especially when we use aggregate data – small firms in what may be emerging activities and large firms which have invested in the development of new services, equipment or product advances in a manner which is atypical for their industry.

Experimenting with micro data

Methodologically, there are few options. Small surveys can provide intensive data and case studies of particular firms or we can develop or find extensive data files: the latter which is reported in this paper is very much the less costly strategy. Survey information on *individual enterprises* producing new technology-based products has been obtained from a relatively recent, proprietary database on the high-technology products of Canadian firms – *Cantech* (Hutchinson Research, 1991). The structure and organization of this file, which is still being expanded in its coverage, is derived from *CorpTech*, its forerunner in U.S. It has provided a rich, and unique source of information on over 2,300 firms whose output is described by codes for over 30 high technology service, software or hardware product groups (Table II). *Cantech* combines records from geographic cluster samples of firms with a national coverage of large firms. Within the limits of this form of survey, it has a representative coverage of Canadian high-technology enterprises and allows comparative inquiries for a small number of urban centres where the full size range of firms has been surveyed. This file provides a coverage of about 68% of Canadian companies undertaking R&D and reported in the data published by Statistics Canada (1993). Its chief limitation as a database is its uneven locational coverage but its particular advantage is information on the multiple products of individual firms.

TABLE II
High-technology product groups

Goods and service products	Number of firms
Manufacturing:	
Defense/military equipment	26
Manufacturing equipment	26
Pharmaceutical	34
Medical equipment	59
Photonic equipment	59
Biotechnology systems	68
Chemicals	89
Transportation equipment	89
Factory automation	127
Advanced materials	132
Telecommunications	161
Computer hardware	162
High technology nec	166
Energy/environmental equipment	198
Test/measurement/control equipment	235
Subassemblies/subsystems	241
Computer software:	724
Services:	
Artificial Intelligence	7
Energy	14
Materials	29
Test/measurement/control	30
Automation	41
Chemical	43
Education/training	50
Telecommunications	55
Electronics	71
Biotech	72
Transportation	89
Environmental	116
Manufacturing	177
Engineering/design	182
Computer services	507
Total number of firms	2344

Source: Hutchinson Research, *Cantech Database*, 1991.

Technology clusters

Various levels of generalization are possible in identifying technological strengths: McFetridge (1993), for example, in referencing a fragmented literature on the subject reports descriptions which range from broad categories to specific product systems. Here, it has been possible to be more systematic. Packaged for users as a relational database, *Cantech* provides information on the products of each firm thus allowing a "search" for firms indicating that they produce particular product technologies or combinations of products. Employing multiple-counting of products, it was established that 51% of firms supply services, 31% produce software and 77% of respondents produce goods. The first research goal was to discover appropriate combinations of product technologies so as to provide a simpler account of the output of the respondent firms. Groups of products have been assembled that describe the output of sets of firms; they have related uses (markets) although they may not coincide with recognised industries. The outcome of this process has been to define *clusters of technologies* (Table III) that identify the joint output of products by firms.

TABLE III
High-technology clusters

Technology clusters	Total firms in this cluster	Firms in only this cluster
Biotech-pharmaceutical	187	111
Information technology	1155	804
Automation technology	378	107
Chemicals and services	121	41
Advanced materials and services	157	58
Transportation	116	26
Energy-environmental technologies	709	247
Generic technologies	590	174

Note: Defense, Defense services, Photonics, and Photonics services did not meet the criteria for inclusion in the technology clusters although it was expected that they would be part of Information Technology.
Source: Hutchinson Research, *Cantech Database*, 1991.

The process of studying these technological commonalities was begun with a list of 14 key Canadian technologies identified by the Science Council of Canada, and the technological strengths reflected in the results of a survey of large R&D performers (Statistics Canada, 1989b). Given these earlier results, clusters were expected to involve biotechnology (probably with pharmaceutical and possibly with chemicals), computer hardware and software (possibly with telecommunications), advanced materials, machinery, transportation equipment (particularly aircraft and parts) and, energy production equipment. The clustering methodology began with an evaluation of the product groupings implicitly identified in these studies, using the data for firms responding to the *Cantech* survey. Then, other product groups were added to the starting groups. The attempt was made to be consistent in forming clusters; in particular, a product was added to the definition of a cluster only if a minimum proportion (40%) of the firms already assigned were found to provide the additional product. Furthermore, a reevaluation of the clusters after they had been formed in this way ensured consistency in the joint processes of grouping products and assigning firms. While this rule of inclusion is largely arbitrary, it helps to determine the size and number of clusters and it was chosen because it produced a technology classification that is consistent with international experience and other sources of information on Canadian technological strengths. The clusters (Table III) used for further analysis meet this standard of plausibility; this applies even to the Generic cluster which has been defined to accommodate firms supplying Subassemblies and Consultant services. They have very complex patterns of co-production which is understandable since these products are inputs to many other economic activities. Only a small number of product groups could not be assigned to clusters. The broad *Information Technology* (IT) cluster has the largest number of member firms reflecting the existence of many small software and hardware suppliers. More importantly, computer services, software, and hardware are co-produced and the majority of firms making telecommunications equipment and providing related services belong to this multifaceted focus of industrial activity. Other data on software producers (Statistics Canada, 1990c) confirm this interpretation; 60% of expenditures on software R&D are made in the telecommunications and business machines industries. The *Energy-Environmental* (E-E) cluster contains the second largest number of firms and covers a wide range of related products and services including test/measurement and control equipment and services, energy services and energy/environmental equipment. When the number of firms is taken as the measure of scale, these two clusters and those labelled as *Advanced materials* and *Biotechnology-Pharmaceutical* (B-P) identify the main high-technology foci of Canadian industry.

The clusters describe the way Canadian industry has responded to new and expanding technology paradigms (Freeman and Perez, 1988) such as information technology, biotechnology and nuclear technology and understandably these are not well represented by industrial classes. Some activities included among the clusters have their origins in earlier phases of industrial development and are responding to new knowledge and producing new products. In the case of Chemicals, Advanced materials and Transportation equipment this accounts for the presence of more firms that are *older* as well as *larger* (Table IV), some of them having attained their large scale by producing for well established commodity markets. Nevertheless, through R&D they have expanded the mix of their industrial activities to include new technology based products; for example, minerals processors are also involved in the production of advanced materials. Thus, some resource firms are renewing their technologies and Canada's older industrial strengths are the origin of firms producing high technology products.

The clusters also show that Canada has shared in the wave of new technology-based firms (NTBFs) experienced in all industrialized economies (Rothwell and Zegveld, 1982, 1985). The incidence of these small firms varies considerably across the technology clusters, the newer activities in the bottom half of Table IV – Automation,[6] Biotechnology-Pharmaceutical, Information Technology, and Energy-Environmental – having higher proportions of smaller firms, the majority having been established since the mid-1970s. Unfortunately, the expansion of the population of Canadian high-technology firms peaked in the period 1981–85, followed by an apparent decline in the rate at which new firms have been born and survived. This collapse is found in the sample as a whole and in both halves of Table IV since small, recently established firms are found in all technology clusters. While recognised collectively as a base for growth and a source of product ideas and components, individually these firms are fragile and often starved of capital and experienced management.

The activities with higher proportions of large firms (Table IV) contain more companies which are pre-1971 survivors. While this pattern reflects the truism that firms take time to grow, it also verifies that some of Canada's older and larger firms have adopted new-technology based products as a way of evolving from their former product mix. Those clusters in which there is a higher incidence of R&D labs employing 100 or more are also in the upper part of Table IV and are the activities which have higher proportions of large firms (> 500 employees) and businesses established before 1970. Nevertheless, large firms occur in all of the activities, as do large labs, showing that Canada's high-technology specializations are established well enough to have produced relatively large firms in all of them.

Information technology

IT has a very large in number of firms ranging in size from very large to ultra-small. Although it embraces in one cluster the industries responsible for about 35% of Canada's industrial R&D expen-

TABLE IV
Distribution of firms in high-technology clusters

Technology clusters [% firms by cluster]	Employment				Year established		R&D staff	
	< 20	< 50	≥ 500	≥ 1000	≥ 1976	≤ 1970	≥ 100	≤ 4
Chemicals	26	44	13	10	38	53	12	47
Advanced materials	27	41	13	9	38	53	10	52
Transport. equip.	26	42	19	10	34	45	14	37
Generic	38	55	11	7	54	33	9	50
Automation	46	68	5	2	50	36	4	63
Biotechnology	52	64	4	1	62	24	3	47
Information tech.	62	79	4	2	76	10	3	58
Energy-environmental	46	68	6	3	53	32	5	58
Total	51	69	7	4	63	24	5	57

Source: Hutchinson Research, *Cantech Database*, 1991.

ditures, its logic derives from the complementary technologies which are used. It is significant that Canada has an international foothold in IT given the importance attached to the future expansion of this activity (Freeman and Perez, 1988). The cluster includes the telecommunications equipment industry, other electronic equipment, business machines, and computer services. Software R&D, which is particularly important among firms in the cluster, now comprises 25% of Canadian industrial R&D expenditures; 44% of this is undertaken as part of telecommunications and electronics activities. Smaller expenditures on software R&D are made by the computer hardware industry (16%) while the computer services industry (15%), and other service activities such as engineering and scientific services are responsible for 12%.

The connections between electronics (including semi-conductors and components, avionics, lasers and other applications areas), computer hardware, software and services, and telecommunications systems elements are very close with various combinations comprising the activities of both the main firms and smaller enterprises. Telecommunications, however, is the core of Canada's IT cluster if only because of the importance of Northern Telecom (NT) which is about 16 times larger than the second largest firm, Mitel. NT alone performs about 21% of Canada's industrial R&D. It is also the largest Canadian producer (about 50% of output) of semi-conductors which it makes wholly for its own use. In contrast to this, Mitel predominantly sells its output of semi-conductors to other firms (Science Council of Canada, 1992, #14). Although semi-conductor design has been an important means of attaining an advanced position in telecom technology, and has been a necessary requirement for success in domestic and international markets, it is not a sufficient condition. Firms now integrate their products with services such as network design and planning, and operational analysis and support, and these are very large opportunities for software development.

Three types of firms have emerged in the Telecommunications industry (Science Council of Canada, 1992, #1).

Product development companies – small and medium sized firms such as Gandalf and Newbridge which focus on particular international market segments. Software, often used as firmware, is the major vehicle for their innovations. On their own these firms have "disjointed capabilities" (ISTC, 1991b) and the ability of other firms to integrate systems is important.

Large system-houses such as NT provide the backbone technologies and software to permit the installation of core network systems and high level services. Telephone companies have been the traditional customers but major new markets are provided by alternate and cellular networks. System-houses serve a market of public carriers which are demanding expanded services and reduced costs. Known for its telecommunications systems, NT operates the largest software laboratory in the country, and Bell-Northern Research, its R&D subsidiary, devotes 80% of its R&D to software development (Science Council of Canada, 1992, #15).

Systems Integrators are drawn from the ranks of major computer companies (such as DEC and IBM) or telecom equipment suppliers, but increasingly competition is being mounted by "non-aligned" firms which can supply independent advice and design communications systems for individual customers (Science Council of Canada, 1992, #7). In Canada, IBM is the second largest software firm, and its software lab is the third largest in IBM. Since the company is moving its primary focus to systems integration and software development it is significant that the Canadian lab is emerging as one of IBM's growth centres.

Energy-environmental technologies

This is the second largest cluster of firms and it reflects the close ties that have developed between the energy and environmental components as a result of geographic and historical factors of development; for example, having developed skills in energy projects, mining, forestry, transportation as well as municipal services, Canadian consulting engineering services have expanded the range of their activity. Thus the cluster exhibits a composite of strengths concerned with engineering and design services related to energy projects, environmental and industrial testing, and monitoring services and the development of equipment. The weaker part of the cluster occurs in the production of capital equipment. In the Canadian electrical manufacturing industry, for example, imports exceed exports by a ratio of nearly 3:1, most manufacturers are foreign-owned, and the 2.5% of sales spent on R&D is low by international standards (Science Council of Canada, 1992, #12).

There are four major product areas in the E-E cluster (Science Council of Canada, 1992, #13). First, in the energy field, there is the design and management of large scale hydro-electric projects (in which the lead firm is SNC-Lavalin supported by equipment suppliers such as General Electric Canada) and there are nuclear power stations. About 6% of the world's large nuclear reactors are Canadian CANDUs, many operated by Ontario Hydro, Hydro-Quebec, and New Brunswick Power. This system is designed by AECL Research which is the major technological asset of the electric-power machinery industry (Science Council of Canada, 1992, #12). Several firms in the oil and gas sector have the expertise to manage large projects and Canada has developed the extraction technology for heavy oil, and oil sands, and sour gas reserves. Second, in the design of paper-and-pulp plants, including recycling and co-generation, Canadian capacity is significant because of the rapid escalation in environmental standards. Third, there is a wide range of environmental engineering projects including the disposal of mine-tailings and recycling and waste-disposal in a variety of industries including petro-chemicals. Fourth, there are many small enterprises in the E-E cluster connected with resource exploration and development (mainly in Western Canada) and with providing products that allow industry to meet environmental standards which are themselves an outcome of environmental legislation. Some parts of this cluster are consistent with developments in IT and environmental policies that Freeman (1992) explains are reducing energy and materials intensity and which contribute to sustainable development.

While the activities of two thirds of the firms in the sample are described by one of the product clusters the remaining one-third of the sample firms is best described by product combinations which place them in two or more clusters. These combinations reveal additional commonalities of technologies realised by industrial firms that are produced by technological complementarities and/or by managerial strategies.[7] When these inter-cluster ties are analyzed, three broad areas of development are recognised that connect all technologies. The central position of the Energy-Environmental cluster among these ties conveys both the importance of this group of activities and the technological diversity of the firms that are involved (Figure 1). This may be a peculiarly Canadian variant of the emerging international "environmental industry". Since firms created to produce or manage energy production systems and to provide consulting services have expanded into the area of environmental controls, it is understandable that many of the firms have technological bases in automation (capital) equipment, engineering and IT (generic and IT clusters), or biotechnology (e.g., mineral extraction from mining waste and remedial action on oil-spills).

Location of high technology activity

The long-term impact of new technologies on the location of economic growth has been illustrated historically by Freeman and Perez (1988) who explain why, over the long term, many sets of locations have been relegated to the industrial backwater by technological change. In cases involving more limited time-spans, however, infrastructural assets have permitted the adjustment of locations to new technologies and have provided assistance for the process of change. This is especially true for major centres of agglomeration. Therefore, some of the major questions asked about technological innovation focus on geographic explanations of its incidence and on definitions of supportive technological infrastructure (Feldman and Florida, 1994). Although there is, at best, an imperfect identity linking new locations with industrial innovations some locational enquiries inevitably focus on the new.

Over the last three decades a major public relations and promotional industry has emerged based on attempts to develop or to recognise emergent regional high-technology complexes (Malecki, 1987). In this vein in Canada, great success has been claimed for the Ottawa region – as Silicon Valley North[8] – but it has never been clear whether its specialization on telecommunications has established it as having attained international significance or whether its early promise has continued. The alternative perspective would point

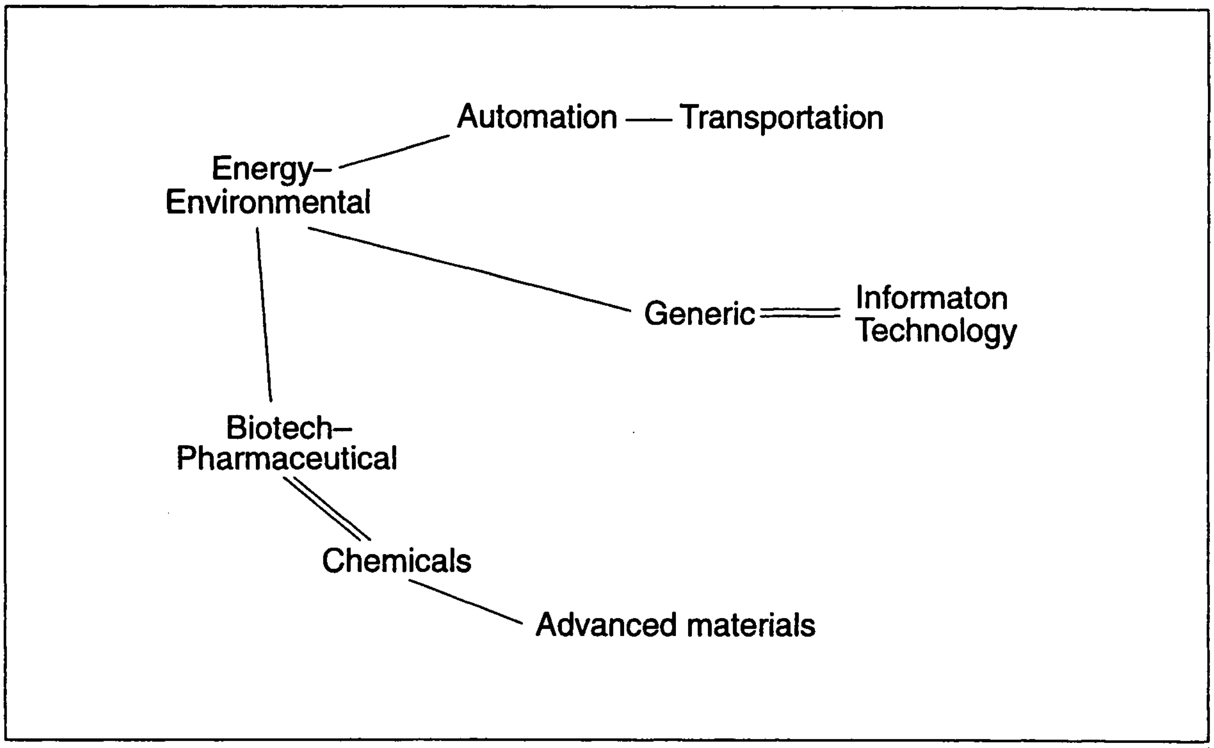

Fig. 1. Connections between product clusters.
Note: The data used for this figure are derived from the number of firms whose products occur in two or more clusters. The largest of these values, in each column of the matrix of clusters arrayed against their counterparts, is used to provide a directed graph of associations between technology clusters using the criterion of largest association in each column of the matrix. Because variation in the number of firms in each cluster affects the measurement of association, the data have been standardized (row-wise percentages): the only linked pairs of clusters are Generic-Information Technology and Biotech-Pharmaceutical.

to the great importance of the major metropolitan centres as origins of technology intensive firms. One of the problems that has limited serious inquiry on the location of innovation has been the lack of data that would allow detailed regional comparisons across the Canadian urban system.

Nevertheless, Canada has a simple aggregate location pattern of technology intensive activity. At the Provincial level R&D is localized in Ontario where 56% of expenditures are made compared with smaller proportions of population and provincial GDP though manufacturing value added has a similar degree of localization. Another 27% of R&D occurs in Quebec followed by British Columbia (7%) and Alberta (6%) (Table V). Unfortunately, public data provide a very limited account of the location of software producers and producer service firms and allow no possibility of undertaking detailed analyses. The location of secondary manufacturing seems the key to understanding the R&D pattern because it is the dominant performer of R&D and is highly localized. Ontario's share of manufacturing value added dominates in every industry except Aircraft and parts in which it slipped from 41 to 35% (1975–92) in favour of Quebec; in every other industry, Quebec is the second most important, though in absolute terms the difference is usually considerable (Table VI).

The number of high technology establishments generally has grown faster in the central provinces, exceptions being the growth in the number of Alberta firms manufacturing machinery, and the emergence of pockets of expertise in IT in British Columbia (ISTC, 1991b). Given this localization of technology intensive industry in Central Canada and knowing that the federal government is responsible for major expenditures on R&D, attempts to achieve some spatial redistribution might have been expected, but 50% of its expen-

TABLE V
Provincial distribution of research and development expenditures

	Industrial R&D expenditure 1990 (%)	Population 1990 (%)	GDP 1990 (%)	MVA[a] 1989 (%)
Atlantic Provinces	1.7	8.7	6.1	3.8
Quebec	27.2	25.8	23.0	26.1
Ontario	55.6	36.6	41.3	52.8
Manitoba	1.0	4.1	3.6	2.3
Saskatchewan	1.0	3.7	3.0	1.0
Alberta	6.3	9.3	10.6	5.0
British Columbia	7.2	11.8	12.1	8.8
Yukon and N.-W. Territories	0.1	0.4	0.3	< 0.1
Total	$5.105 billion	26,610,000	$670 billion	$135.7 billion

[a] Manufacturing value-added.
Sources: Statistics Canada, 1992; Industry, Science and Technology, Canada, 1991a; Statistics Canada, 1989a.

TABLE VI
Canadian manufacturing value added: Selected industries (% Canada by industry)

Industry	Ontario			Quebec		
	1975	1990	1992	1975	1990	1992
Telecommunications equipment (SIC 3351: 1975)	58.1	66.4[a]	63.5[b]	32.2	na	19.6[b]
Computers and peripherals (SIC 3361)	89.0	66.0	68.6	10.7	17.3	16.0
Scientific and professional equipment (SIC 391)	83.6	76.2	78.8[c]	11.0	na	10.8[c]
Aircraft and parts (SIC 3211)	40.8	33.6	34.5	47.3	54.3	50.5
Pharmaceuticals and medicines (SIC 374)	54.6	51.8	49.3	43.8	46.9	48.6
Machinery (SIC 31)	62.3	56.2	52.4	na	19.1	23.3

Notes: [a] 1989 data; [b] SIC 3358; [c] SIC 3911+3912+3914.
Sources: Statistics Canada, 1975, 1989a, 1990d and 1992.

TABLE VII
Technology intensive manufacturing: Metropolitan Centres, 1986

Industry	Toronto	Montreal	Canada
		$ 000,000	
Computers and peripherals (SIC 3361)	300	150 (SIC 336)	834
Communications equipment (SIC 3341, 3351, 2, 9)	1,444[a]	922[a]	3,174
Pharmaceutical and medicine (SIC 3741)	775	778	1,885
Aircraft and parts (SIC 3211)	544	na	1,956
	544	830	1,711 (1985)
Scientific and professional equipment (SIC 391)	596	na	1,050
Machinery (SIC 31)	939	345	4,249
Other electronic equipment (SIC 337, 3399)	483	91 (SIC 337)	1,324
Total	na	na	14,472
All manufacturing	22,952	14,521	102,459

[a] Estimated as 3359 + "Other" Electrical and Electronic products.
Source: Statistics Canada, 1986.

ditures are made in Ontario; one reason is that Ottawa is a substantial concentration of government R&D labs. Ottawa's concentration of Government R&D labs and the federal government market for IT have stimulated a variety of private sector investments specialized in Business machines and Telecommunications equipment but the employment this generates is only 10% of that of Toronto.

Toronto (26% of 1990 R&D expenditures) is the leading urban centre in industrially funded R&D, followed by Montreal (23%) and Ottawa (17% – 1986 data). Toronto and Montreal are also, by a wide margin, the major locations of high-technology manufacturing production (Table VII). Although Toronto has a larger share of most high-technology industries, and Montreal is very much the smaller player, in the Aircraft and parts industry Montreal's share is 1.5-times the size of that in Toronto, while in Drugs and medicine the two centres have attained about the same scale. These regions have similar numbers of high-technology manufacturing establishments but probably twice as many are employed in Toronto as in Montreal, the larger average size of establishments in Toronto in most industries being a product of several influences including the localization of foreign subsidiaries and large indigenous firms. The explanation for this pattern involves Toronto's hierarchical position within the Canadian urban system, its core role in the industrial development of southern Ontario, the size and depth of the Toronto labour market, and its other agglomeration advantages which reflect substantial industrial scale, diversity, and range of producer services.

Urban technology structure

While comparative analysis of high-technology development across the urban system has been difficult, it is possible to verify major scale differences in technology-intensive activity between Toronto and Montreal and the other regions of Canada. Montreal, for example, has 595 industrial R&D units while Toronto has 733 (about 20% of the national total), about 2.5 times the number found in the Ottawa region and 3 times that in Alberta. Using *Cantech* it is possible to begin to make additional comparisons of technological development between some centres particularly between Toronto, Ottawa and Calgary and Edmonton.[9] The distribution of large enterprises is a strong influence on the location of new-technology related jobs and Toronto is well served with as many firms employing 1,000 or more as the other smaller centres combined (Table VIII). When the size distributions of the four centres are compared the expected very high proportions of firms employing fewer than 100 is the common element. Ottawa and Toronto, however, are distinctive. Ottawa has many more large firms than the other smaller centres while Toronto has provided the environment where a relatively large group of middle-sized firms (100–999 employees) could emerge.

TABLE VIII
Size distribution of high-technology firms: Selected urban centres

Employment	Toronto	Ottawa	Calgary	Edmonton
Size of firms	No. of firms			
< 100	561	118	247	178
100–999	106	13	26	18
1000 ≤	26	16	12	3
Total	693	147	285	188
	% of firms			
< 100	81	80	87	89
100–999	15	9	9	9
1000 ≤	4	11	4	2
Total	100	100	100	100

Given the diffusion of technology-intensive industry in U.S. from its former core regions it might be assumed that Canadian high-tech industry might have begun in the major industrial centres and then became established in other places as new production opportunities and markets were identified. Toronto's longer industrial history is reflected in the large number (98) of its current firms engaged in technology-intensive production that were established before 1960 and these firms continue as one of Toronto's high technology advantages. Since about 1970, however, there has been substantial growth in the number of technology-based firms in Canada (see above) but by no means has new-product entrepreneurship in other centres meant the eclipse of

Toronto (which has generated 600 new firms since 1970). Nevertheless, Toronto has shared growth with other regions.

In addition to differences in scale of industrial development between the four centres, there are distinctions in their technological specializations. The largest proportions of firms in the Energy-Environmental cluster are found in Calgary (44%) and Edmonton (47%) reflecting the regional significance of oil and gas, and forest products while the order is changed in favour of the Information Technology (IT) cluster for Toronto (57%) and Ottawa (63%). The rise of the IT cluster marks the different industrial histories of the four urban centres (Table IX). IT emerged as the dominant source of new firms in Ottawa and Toronto 1971–75 while in Calgary and Edmonton, it was not until the late-1970s before activities such as computer assembly made as large an impact. Considering that the primary phase of innovation in microelectronics and computer systems occurred in the 1960s (Boston and San Francisco regions), successive delays can be perceived in the time at which secondary (market) innovations generated changes in the economic activities of Canadian urban centres.

Ottawa

With 63% of its enterprises in the IT cluster (including all of its large firms), Ottawa is the most specialized of the four centres and this has led to international comparisons with other new technology-based complexes (Steed and De Genova, 1983; Steed, 1987). It has built its reputation on spinning-off new technology based firms, though some small firms subsequently have moved to larger market nodes such as Toronto (Steed, 1982). Ottawa is distinctive in the number of firms that have been generated given their origins were a small number of Canadian core firms in telecommunications, computers, software and computer services. The failure of Microsystems International (a subsidiary of what would become Northern Telecom) proved to be of considerable importance in spawning new firms in the mid-1970s but the research labs of Northern Telecom (Bell Northern Research) have been a more recent source of spin-off firms. Federal government labs have been an important source of contracts – especially the Department of Communications – for small and large firms in telecommunications and electronics. Evidently, Ottawa has capitalized on a variety of advantages which are not available to any other urban centre in Canada but the circumstances are sufficiently different to nullify its potential as a model of development that could be emulated by any other urban region.

Toronto

As a result of the scale of its consumer and industrial market, Toronto, the centre of Canada's major industrial region (southern Ontario), has been Canada's largest magnet and generator of new technology based firms and locus of corporate growth. But its economic geography has shifted

TABLE IX
Information technology firms: Selected urban centres

	Canada	Toronto	Ottawa	Calgary	Edmonton
	% current IT firms				
Before 1971	10	9	8	10	9
1971–75	13	12	18	15	7
1976–80	24	22	20	33	28
1981–85	37	40	41	27	43
1986–91	16	17	13	15	13
Total	100	100	100	100	100
# current IT firms	1145	395	92	124	86
IT %	49	57	63	44	43

Source: Hutchinson Research, *Cantech Database* (1991).

substantially over the past 30 years, traditional manufacturing industries have been in decline and this process has been accelerated by the recessions of the early 1980s and 1990s. Despite technology-intensive growth, the share of manufacturing employment has declined over the period 1976–1993 from 26 to 17%, while services have grown (28 to 38%) as has finance and insurance (8 to 11%).[10] Rising productivity in manufacturing, and the shift of some head offices from Montreal to Toronto in the late 1970s have supported these trends as has a structural shift in the metropolitan economy towards managerial and professional jobs especially in the producer services.

Previous research using labour force data for Canadian urban centres (Coffey and McRae, 1989; Coffey, 1993) suggests that the growth of producer services is registered most strongly in the largest urban centres and, as was noted earlier in Table I, technology-intensive services are a component of this trend to high order services. The locational generalization which seems to apply to producer services is that they are highly localized among Canadian centres with 300,000 population and over. Within this group of 10 urban centres, services are more localized than manufacturing production and Toronto and Montreal together are responsible for 39% of the jobs in Finance and Insurance and Producer services compared with 36% of manufacturing value added (Table X). Technology-intensive activities however, are even more localized with about 50% of industrial R&D expenditures being made by firms in Toronto and Montreal. Thus Toronto is not only the largest centre of R&D and advanced manufacturing production but also, by inference, the major location of technology-intensive services and software production.

TABLE X
Metropolitan centres: Indicators of economic structure

	MVA[a] 1986	#R&D units 1990	Fire and PSA[b] jobs 1986	R&D expenditures 1990
	% Canada			
Toronto	22	20	25	26
Montreal	14	16	14	24
Ottawa	1	8	8	18[c]
Total %	38	44	47	68

[a] Manufacturing value added.
[b] Producer service.
[c] Estimated from 1986.
Source: Various publications, *Statistics Canada*.

Further research on technology intensive services is constrained, however, by the paucity of databases on the activities of service firms. Using data derived from *Cantech* it is possible to generate basic information on both software producers and technology intensive service firms for Toronto. Within this definition of services, the contemporary specializations of the region are the outcome of the evolution of a mix of activities each of which is marked by the dates at which the number of new establishments peaked. Manufacturing service firms were established primarily in the 1970s while the peak for design and engineering occurred during the late 70s and early 80s. Computer service firms date from the early 1970s and peaked in the 1981–85 period but the record of new establishments has continued strongly as it has for Software. Environmental services, however, are a development associated with the most recent period, 1986–91, and are expected to grow as environmental legislation requires firms to seek the input of consultants in modifying their processes, products, and working conditions. Given the importance of the whole IT technology cluster in Toronto it is not surprising that within this, computer services and software producers are the most highly developed services within an evolving range of activities. The origin of this development rests on Toronto's variety of national head-office functions. Associated offices and services have been developed and consequently, there is a strong local and regional market for new technology based products especially those based on computer and software services and software services and products. The development of Toronto's high-technology sector not only illustrates the localization of industrial R&D and the output of high-technology manufactures but also the importance of services as markets and as sources of technology intensive products. This is an important dimension of the attraction of new-technology based activities to Toronto. Accompanying these changes has been the spatial evolution of the metropolitan region to accommodate new activities and their growth. As traditional manufacturing production was lost from the central area (corresponding to the City of Toronto), service sector employment in financial firms and in a variety of national head offices for the broadest spectrum of companies grew. The proximity of refurbished commercial and industrial space to the large commercial office core of the region has been an asset that has attracted small service and software firms (employing less than 50) and thus the central area has been able to compete with suburban and peripheral areas.

Simultaneously, the suburban "ring" and an ever expanding ex-urban "fringe" have enjoyed successive waves of economic growth that have defined the structure of the metropolitan economy as one in which a wide range of technology-intensive activities has new importance. Using this simplified geographic structure (Table XI) the core of the region is found to have a service-software specialization and a strong representation among the region's large employers. The other two zones are, however, the source of most of the region's growth with five locational clusters generating the vast majority (88%) of the region's technology intensive firms. These locations are the outcome of a mix of factors including industrial zoning, the actions of the property development industry, the desire by firms for access to the international airport and, for this reason and others, proximity to Toronto's peripheral expressways, and the influence of locational pioneers which have localized potential suppliers of components and service firms and firms seeking visibility by locational association.

Conclusion

The examination of micro-level data to identify technological clusters has identified the structure of the technology-intensive sector of the Canadian economy. The activities which are embraced by this definition contain some strong companies – both indigenous and foreign. Most firms in each cluster are small indicating that there is considerable entrepreneurial activity. In recent years, however, there has been a sharp decline in the number of new firms and often the venture capital industry reports a shortage of attractive firms. Although there has been growth in technology-intensive activity in Canada, macro-economic indicators suggest that industrial firms do too-little R&D. As a reflection of the rate of innovation and aggressiveness in international marketing, this is probably symptomatic of business practises across a wide range of old and new activities. Consequently, it appears that no activity unequivocally meets criteria of strong growth and improving, positive trade performance.

One interpretation of this may be that Canada is spreading its technological resources too thinly. It has been assumed by many that North American free trade will provide the stimulus of a larger market but it is quite unclear how well Canadian firms can respond and there is an additional problem: free trade simultaneously opens Canada's existing high-tech sector to even more focused acquisition interest by foreign, especially U.S. firms.

The results of the cluster analysis imply that the

TABLE XI
Toronto metropolitan region: Locational structure of high-tech activity

	Total # firms	# firms > 1000 employees	# firms < 50 employees	# service firms	# software firms
			% firms		
Core	21	27	24	27	28
Suburbs	39	42	37	38	35
Periphery	40	31	39	35	37
Total	100	100	100	100	100
			# firms		
Total	695	26	427	327	239

Source: Hutchinson Research, *Cantech Database* (1991).

technological development of some firms occurs by means of their skill in combining related product technologies. This supports diversity in that many technologies are shown to be connected with others through the production arrangements of individual firms. It explains why a substantial proportion of Canada's innovative firms have been in existence for some time, often in the resource industries or associated with them, and they are responsible for the extension of the profitability of Canada's economic staples through the application of technology to the resource sector.

Other evidence points to the strongest technology-intensive activity occurring in IT. Within this technology cluster, the computer hardware industry generates a trade deficit while telecommunications has emerged as an international strength. It should be noted that while there has been major growth in the services, most firms supply the regional services market and are not likely to modify Canada's services export pattern. Nevertheless, software producers have been successful exporters.

Firms in Toronto and Montreal together with those in the Ottawa region perform about 68% of Canada's industrial R&D and provide the core of Canada's high-technology production. Among these centres, Toronto has been used to explore the reasons for the high degree of locational concentration of technology intensive activities. To a large degree the explanation is one based on the agglomeration of the broadest range of economic activities. Most recently, the large scale of its national and regional head offices, its other commercial activities, and its manufacturing have meant that computer services and software firms have become well-established here.

The structure of each of the major high-technology centres includes large firms and small enterprises and on the evidence presented each seems to incubate new firms. Large firms, however, have a weaker presence in smaller centres. Given this and the difficulty of accumulating high-technology infrastructure it seems unavoidable that smaller Canadian locations which aspire to growth in high-technology jobs will remain among the myriad of North American cities that cannot develop the critical mass that will allow this to be a plausible goal. By contrast, Toronto and Montreal have the advantage of substantial agglomeration economies and the record suggests, that the majority of new firms will be born in the major centres or move there in order to capture positive externalities.

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Notes

[1] In some situations they are indistinguishable if only because markets in components and sub-assemblies are extensive (international), and information on patents and standards is widely availability.

[2] These mean that it will probably never match the current aggregate performance of Japan or U.S. The low ratio of R&D expenditures to sales in the resource sectors (e.g., 0.4% in Paper and allied products) and Canada's small R&D expenditures for defence compared with those of U.S., U.K. and France mean that it is unlikely to catch the R&D leaders.

[3] Compared with GDP, Canada provides slightly more public funds for R&D than U.S. and U.K., about the same as Italy and Japan, but very much less than the other OECD countries (Statistics Canada, 1993a). These public funds are spent on R&D in industry, in universities and in government laboratories, the latter reflecting a long-run, policy response to the problems experienced by a small economy with many small firms that have limited R&D capacity. It has been known for some time, however, that the transfer of technology from federal labs is imperfect and as more orthodox economic thought has gained sway, these facilities have often been perceived as deflecting public dollars away from industrial R&D which responds to market processes.

[4] Industries defined as technology-intensive were defined as those with R&D/Sales equal to or greater than 2.5% using 1991 data. The resultant industries correspond to those in related Canadian research see Steed (1982) for an earlier discussion.

[5] The components of the surplus of $10.2 billion on total trade in goods in 1991 were as follows; imports $135.4 billion, exports $145.6 billion. High technology imports were $22.5 billion and exports $14.2 (Statistics Canada, 1991a, b; Industry Canada, 1994).

[6] Given that machinery is a potential origin of some firms producing technologically-advanced production equipment it may seem that Automation is misplaced among the "new" activities. Machinery, however, is a weak performer in Canada and Automation has not inherited older, large firms; neither has it been able to generate them.

[7] In the literature on the product and technological diversification of firms the concept of multi-technology corporation

(Granstrand and Sjolander, 1990) leads us to expect these combinations.

[8] The term was probably coined by Martin Mittelstaedt (1980); it has been used frequently since then.

[9] Data on the location of firms undertaking R&D confirms that the survey's coverage of these locations is adequate.

[10] These data were derived from unpublished tabulations of the Labour force Survey undertaken by Statistics Canada; they were made available by the Metropolitan Toronto Planning Department.

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